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SPACECRAFT OCEANOGRAPHY PROJECT DOCUMENTATION STUDY

Under
Contract No. N62306-70-C-0149
U.S. NAVAL OCEANOGRAPHIC OFFICE
Washington, D.C. 20390

Under Sponsorship of the
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C. 20546

CSC

COMPUTER SCIENCES CORPORATION

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SPACECRAFT OCEANOGRAPHY

PROJECT DOCUMENTATION STUDY

By

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and
Captain B.D. Claggett, USN(Ret.)

Prepared Under Contract No.
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Computer Sciences Corporation
803 West Broad Street
Falls Church, Virginia 22047

November 1970

FOREWORD

This final report documents progress towards achieving a capability to acquire oceanographic information by using remote sensing techniques from aircraft and spacecraft. It is submitted under the terms of Contract N62306-70-C-0149 with the U.S. Naval Oceanographic Office (NAVOCEANO) as modified on 18 September 1969 and 11 May 1970. Funds for the study were provided by the National Aeronautics and Space Administration (NASA) on an interagency transfer of funds.

Emphasis during the conduct of the study was placed on those research activities funded and/or monitored by the Spacecraft Oceanography Project of NAVOCEANO but also includes research and development conducted through other agencies. The organization of the report follows a logical progression of steps that shows the rationale for the program, the progress in acquiring and using the data, and the program's status for achieving a capability to acquire oceanographic information utilizing spaceborne instruments.

The study was conducted under the cognizance of the staff of the Spacecraft Oceanography Project (SPOC). John W. Sherman, III is Project Manager and A. L. Grabham was Technical Monitor. Close liaison was maintained by CSC with the SPOC personnel during execution of the contract.

This final report was prepared under the technical direction of:

Dr. W. E. Strange, Director Geospace Applications Operation	R.K. Salin, Manager Geonautics Department

Several individuals involved in various ocean industries and ocean sciences as well as instrument development were querried in regards to their needs, future applications, and progress in remote sensing instrument development. Their inputs were extremely valuable in the conduct of the study. Those individuals contacted are listed in the Appendices.

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SECTION I

INTRODUCTION

1.1 BACKGROUND

The Spacecraft Oceanography Project (SPOC) was established in 1965 through an agreement between the Associate Administrator, National Aeronautics and Space Administration (NASA) and the Assistant Secretary of the Navy (Research and Development). The project was established to develop and coordinate the Oceanography/Marine Technology Applications Experimental Program in conjunction with NASA'S Natural Resources Program. SPOC was assigned to the U.S. Naval Oceanographic Office (NAVOCEANO) for administration, which placed the project in a position to provide liaison between the oceanographic and space communities and provided an experienced contractual organization for the administration of contracts in the oceanographic field.

Since its inception SPOC has directed its efforts toward defining the feasible uses of space technology for measuring oceanic parameters. It has contracted for numerous investigations, tests, and studies in the field of oceanic research. Those reports developed through SPOC funding are listed in the Bibliography, (Appendix A). An annual report was compiled covering the work conducted during the initial year of operation, but reports have not been made in subsequent years. Since the early report, efforts related to the subject have increased to the point where a consolidation of the results of all research by SPOC contractors and related research by user agencies, industry and research institutions is mandatory in order to produce a document clearly defining progress to-date, users, their requirements, sensor state of the art, and possible benefits to be derived from spacecraft oceanography.

1.2 NASA-SPOC PROGRAM OBJECTIVES

The agreement between NASA and the Department of Navy establishing the Spacecraft Oceanography Project called for the development of a program of research studies that would lead to the identification of experiments in

oceanography and marine technology utilizing manned orbiting space platforms (73). In addition the Naval Oceanographic Office, in which SPOC was established, was asked to enlist the support and obtain advice of a broad spectrum of governmental, academic and industrial organizations in defining and designing the technical experiments.

Later an expanded definition of SPOC objectives was developed. These objectives are:

a. To increase man's knowledge and understanding of the mechanisms underlying oceanography by exploiting the favorable and unique aspects of spacecraft (altitude, speed, repeatability) and identifying and defining those features and processes of the ocean which are uniquely suitable to measurement by sensors aboard spacecraft, e.g., the ocean's vastness, inaccessibility and remoteness; the small time-scale variants; the existence of large-scale phenomena, and low topographic relief.

b. To compile and assess information on those instruments and techniques which can provide meaningful and useful oceanographic data from spacecraft, separately, or complementary to other data acquisition techniques; to investigate means for coordinating and optimizing all available methods of oceanographic data gathering from the subsurface, and from above the surface of the ocean.

c. To develop and test new techniques using oceanographic spacecraft observations to fill gaps existing in present techniques; to determine which oceanographic signatures can be quantitatively detected from orbital altitudes, free of ambiguity and environmental noise; to establish reliability by comparison with ground truth.

d. To develop new and improved methods of displaying oceanographic information on a global scale suitable for utilization by scientific, technical, and commercial interests for eventual better understanding of the economic geography of the sea and exploitation of the ocean's resources; to develop analytic methods of drawing valid three-dimensional oceanographic inferences from two-dimensional data.

e. To discover, what unforeseen oceanic phenomena may be observable from the overview available at orbital altitudes to scientifically trained astronauts; to assess the degree to which men in a spaceborne system can enhance the system's effectiveness for obtaining and maintaining up-to-date knowledge of the natural conditions existing throughout the world ocean.

f. To exploit the dwell time of all orbiting spacecraft, which spend over two thirds of their total lifetime over the oceans.

Currently SPOC represents the point of contact between the space and oceanographic communities. The project is responsible for contracting for studies of techniques and experiments for collection of oceanographic data utilizing air/spaceborne sensors, the interrogation of in situ sensors by space vehicles, the determination of ground truth, and the analysis of oceanographic data acquired by remote sensors. Both manned and unmanned systems are being considered. Funds for these studies are provided by NASA on a transfer basis to NAVOCEANO who then contracts and monitors the work.

1. 3 STUDY OBJECTIVES

The objectives of the study which led to this report were to:

(1.) Review, compile and document the essential results of all contractual and in-house work performed for and by the NAVOCEANO/SPOC Project from October 1965 to July 1969.

(2.) Evaluate and verify the SPOC results; identify and quantify (where possible) potential benefits from spacecraft oceanography; and compare user requirements with present capabilities.

It was felt that if these two objectives could be met, not only would it be possible to meaningfully assess the results of past SPOC efforts, but it would also be possible to identify the most productive direction for future SPOC efforts.

1.4 STUDY METHODOLOGY

In order to achieve the study objectives a two-phase approach was taken. The first phase consisted of a preliminary review of the 60 documents provided by SPOC at the initiation of the study. This preliminary review had three aims. The first aim was to prepare a review format to be used in the detailed review of the documents. The second aim was to prepare a detailed study plan to guide the total study effort. The final aim was to develop a final report outline as a further means of focusing the study effort.

During the second phase of the study, the SPOC generated documents were reviewed using the review formats generated under the initial phase of the effort. To complete this second phase and provide a means of evaluation and verification of the results, additional documents concerning spacecraft oceanography were reviewed, questionnaires were prepared and sent to potential users and sensor designers and manufacturers, personal interviews were carried out, and the results of all inputs were synthesized in tabular form and evaluated.

1.4.1 Phase I - Preliminary Review of SPOC Documents

A preliminary review of each of the 60 SPOC furnished documents was carried out independently by the project manager and at least one other member of the project team. Each reviewer then contributed his ideas concerning a detailed study plan, a document review format, and a final report outline. The inputs from all reviewers were then synthesized to arrive at the final content of the documents as presented in Appendices B and C of this report. These documents were approved by SPOC before continuing with the study.

1.4.1.1 Document Review Format

The document review forms finally selected and presented in Appendix C were designed to allow summarizing a document in terms of a number of different types of potential information. Allowance is made on the review forms for the following types of information:

(1.) A list of: users identified, user requirements identified, instruments described, data requirements defined, and benefits indentified.

(2.) An indication of the relations between user catagories served and ocean phenomena, between ocean phenomena and the measured ocean parameters, and between sensors and ocean phenomena and parameters. These relations are indicated by checking of proper boxes in four matrices.

1.4.1.2 Detailed Study Plan

The detailed study plan presented in Appendix B envisioned that the second phase of the study would consist of two parts. The first part would be a detailed review of each of the documents provided by SPOC using the document review forms described previously. At least two members of the study staff would review each document. The final results of the reviews would then be transferred to tabular matrices relating in various ways:

. user groups
. user requirements
. ocean phenomena to be investigated
. ocean parameters to be measured
. spatial and spectral resolution requirements
. measurement frequency requirements
. sensor availability and state of the art
. data format, integration, and transmission requirements
. data processing requirements and
. anticipated benefits.

The second part of this second phase of the study would begin with preparation, mailing and evaluation of replies from questionnaires sent to members of the user community, scientific community, and sensor developers. Following the questionnaires, there would be personal interviews with pertinent individuals involved in either utilizing ocean information or acquiring it.

The final objectives of this second phase of the study were to evaluate, verify and document the SPOC documents, identify and, where possible, quantify benefits to be anticipated from spacecraft oceanography, and to compare user requirements and sensor capabilities and thereby establish current state of the art.

1.4.1.3 Final Report Outline

A final report outline was generated and approved by SPOC. This final report is patterned after the outline.

1.4.2 Phase 2 - Review SPOC Documents and Evaluate, Update, and Verify Results

This aspect of the study was carried out as described in the Detailed Study Plan presented in Section 1.4.1.2 and Appendix B.

1.4.2.1 Task 2a - Review, Analyze, Compile, Summarize and Document Reports

Initially SPOC submitted approximately 60 documents for review. An addition to the contract provided 50 additional documents. These documents consisted of reports, investigations, and other scientific and technical papers. The 110 documents submitted by SPOC were reviewed individually by members of the technical staff. The review formats, developed in Task 1, were completed for each document. The principal objectives of this review were to identify the users or potential users of oceanographic data obtained from spaceborne sensors and to determine their specific requirements, to document progress in achieving a remote sensing capability, and to determine the status of remote sensing techniques for ocean studies.

The documents reviewed varied extensively in their worth for providing information to satisfy the above objectives. It was found that, in general, the documents could be divided into two categories. (1) Those that involved the analysis of sensor data or other research applicable to remote sensing of the ocean's surface, and (2) those documents that resulted from surveys of possible applications and potential sensing techniques, or summary discussions

of prior research. The majority of the information used in the report was acquired from those sources reporting original work. However, the survey type documents also proved to be valuable primarily for guidance in determining potential users and their information needs and for guidance to other pertinent activities and reports.

1.4.2.2 Task 2b - Evaluate and Verify Results

The evaluation and verification of the results of the reports and the identification of the user community and their requirements was accomplished through the use of two additional sources of information. These sources were (1) the review of an additional 50 documents, external to SPOC, pertaining to the subject of remote sensing of oceanographic parameters and (2) information obtained from members of the oceanographic and sensor community through mailed questionnaires and personal interviews.

Three sets of questionnaires were developed for this purpose. (1) An abbreviated questionnaire, Appendix D, was developed for the ultimate users of oceanographic information such as fishermen, marine transportation organizations, the petroleum and mineral industry, etc. This questionnaire was designed to obtain current and future (1980) data requirements. (2) The second set of questionnaires (Appendix E) was developed in more detail and was designed for the scientific community, i.e., individuals and organizations conducting oceanographic experiments and research. (3) The final questionnaire (Appendix F) was addressed to sensor designers and manufacturers. It was designed to obtain data on the state of the art of airborne/spaceborne sensors.

Approximately 250 questionnaires were sent to members of the user and scientific communities. (Lists of those individuals and organizations can be found in Appendices G and H.) Approximately 65 of those were returned. Fifty-nine questionnaires were distributed to industry, university and governmental organizations engaged in remote sensor R&D activities (see Appendix I). Twenty-eight were returned for a response rate of 47 percent. This group provided not only the highest rate of return but also the most informative returns.

In addition to the use of questionnaires to obtain information, a number of personal interviews were conducted. Approximately 55 persons that were

either users of oceanographic information or involved in sensor development or oceanographic research were contacted. See Appendix J for those individuals interviewed. For consistency, the questionnaires were used as a format for conducting the personal interviews. As was expected, more complete information was obtained from the interviews than from the mailed inquiries. However, the results of the interviews of some members of the oceanographic scientific community left much to be desired as few could provide precise information on data acquisition requirements. Even fewer had given consideration to the problems of data transmission, storage and analysis or to the benefits that would accrue.

1.5 FINAL REPORT

This final report, thus, contains the results of the study to document progress in the SPOC Program from its inception in 1965 through June 1, 1969. The organization of the report follows a logical progression of steps that shows the rationale for the program, the progress in acquiring and using the data, and the program's status for achieving a capability to acquire oceanographic information utilizing spaceborne instruments.

This logic flow begins with determining the users, both real and potential, of oceanographic information (Section 2), followed by documenting their information requirements (Section 3). These two Sections establish the need for data feasible for remote acquisition. Section 4 discusses progress that has been made towards sensing the various identified phenomena and effectively utilizing the data. Section 5 documents the overall status of remote sensing of oceanographic parameters. The status of information management systems is discussed in Section 6 and the potential benefits identified in the various reports are identified in Section 7. Conclusions resulting from the Study are provided in Section 8.

SECTION 2
IDENTIFICATION OF THE USER COMMUNITY AND THEIR INFORMATION NEEDS

In this section the oceanographic user community is identified and the individual users are grouped. The information needs of the various user groups are then documented in terms of broad information requirement areas. In Section 3 these user requirements are detailed and quantified.

This information is a necessary prerequisite for the evaluation of past research, determination of present status, and definition of future requirements for spaceborne oceanographic sensing systems. Thus it is needed in order to evaluate in context the past research efforts in spacecraft oceanography which were funded by SPOC.

2.1 IDENTIFICATION OF USER COMMUNITY

The first objective of this task was to identify the individual users. The second objective was the grouping of the individual users in ways that reflect some type of commonality of requirements.

In order to satisfactorily identify and group the oceanographic user community an iterative procedure was adopted. Early in the study the initial user and information groupings indicated in Table 2-1 were developed by the CSC investigators in conjunction with SPOC personnel. These groupings were based on past experience of the CSC personnel and the initial review by CSC of the documents provided by SPOC for evaluation under this study effort. These documents, varied from detailed contractor reports to brief papers presented at scientific meetings and/or published in technical journals. The groupings which evolved represented a best judgement of the individuals involved as to the broad major categories in which the users and their information requirements might be consolidated and classified. Only non-military users were considered since military oceanography was outside the scope of the present study.

In Table 2-1, the basic groupings of users are related to the type

TABLE 2-1
THE OCEANOGRAPHIC USER COMMUNITY AND THEIR AREAS OF INTEREST
(PRELIMINARY)

PHENOMENA / PARAMETERS — OCEANOGRAPHIC USER COMMUNITY

	Oceanographic User Community	Marine Organisms (1)			Pollution (2)					Water Temperature		Sea State (Wave)			Currents (Horizontal, Vertical)		
		Extent	Type	Amount	Extent	Quantity	Velocity	Direction	Content	Surface	Subsurface	Height	Length	Direction	Velocity	Direction	Extent
INDUSTRY	Petroleum Exploration, Drilling, Producing											x	x	x			
INDUSTRY	Ocean Mining and Exploration											x	x	x			
INDUSTRY	Shipping and Towing Optimum Routing											x	x	x	x	x	x
SCIENTIFIC NON-GOVERN'T	Universities and Oceanographic Researchers	*	*	*						x	x	*	*	*	*	*	*
SCIENTIFIC NON-GOVERN'T	Fishing Commissions	x	x	x	*	*	*	*	*	x	x	x	x	x	x	x	x
SCIENTIFIC GOVERNMENT-NON-MILITARY	Bureau of Commercial Fisheries, Bureau of Sport Fisheries and Wild Life, State Fishing Agencies	x	x	x	*	*	*	*	*	x	x	*	*	*	*	*	*
SCIENTIFIC GOVERNMENT-NON-MILITARY	Environmental Science Services									x	x	x	x	x			
SCIENTIFIC GOVERNMENT-NON-MILITARY	Bureau of Mines																
SCIENTIFIC GOVERNMENT-NON-MILITARY	U.S Coast Guard									x	x						
SCIENTIFIC GOVERNMENT-NON-MILITARY	National Aeronautics and Space Agency																
FISHING	Commercial Fishing Companies, Commercial Fishermen, Sport Fishermen	x	x	x	*	*	*	*	*	x	x	x	x	x	x	x	x
COASTAL ZONE INTERFACE	Port and Harbor Authorities				x	x	x	x	x			x	x	x	x	x	x
COASTAL ZONE INTERFACE	Federal Water Quality Administration, State and Municipal Water Quality Agencies	x	x	x	*	*	*	*	*	x		x	x	x	x	x	x
COASTAL ZONE INTERFACE	Land Conservation and Resource Agencies											x	x	x	x	x	x
COASTAL ZONE INTERFACE	Land Development and Management Organizations	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
COASTAL ZONE INTERFACE	Recreational Developers and Operators	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

	Oceanographic User Community	Sea Ice			Icebergs		Heat Energy Exchange	Color	Depth		Tides		Geoid	Mean Sea Level	Sea Slope
		Extent	Thickness	Type	Velocity	Direction	Temperature	Color	Bathymetry	Bottom Contour	Height	Period	Sea Surface Geometry	Sea Surface Geometry	Angle of Slope
INDUSTRY	Petroleum Exploration, Drilling, Producing	x	x	x	x	x		x	x	x	x	x			
INDUSTRY	Ocean Mining and Exploration	x	x	x	x	x		x	x	x					
INDUSTRY	Shipping and Towing Optimum Routing	x	x	x	x	x			x	x	x	x			
SCIENTIFIC NON-GOVERN'T	Universities and Oceanographic Researchers	*		*			x	*	*	*			x	x	x
SCIENTIFIC NON-GOVERN'T	Fishing Commissions							x	*	*					
SCIENTIFIC GOVERNMENT-NON-MILITARY	Bureau of Commercial Fisheries, Bureau of Sport Fisheries and Wild Life, State Fishing Agencies							x	*	*					
SCIENTIFIC GOVERNMENT-NON-MILITARY	Environmental Science Services	x	x	x					x	x					
SCIENTIFIC GOVERNMENT-NON-MILITARY	Bureau of Mines														
SCIENTIFIC GOVERNMENT-NON-MILITARY	U.S Coast Guard	*	*	*			x	x							
SCIENTIFIC GOVERNMENT-NON-MILITARY	National Aeronautics and Space Agency														
FISHING	Commercial Fishing Companies, Commercial Fishermen, Sport Fishermen								x	x					
COASTAL ZONE INTERFACE	Port and Harbor Authorities								x	x	x	x			
COASTAL ZONE INTERFACE	Federal Water Quality Administration, State and Municipal Water Quality Agencies							x	x	x	x	x			
COASTAL ZONE INTERFACE	Land Conservation and Resource Agencies														
COASTAL ZONE INTERFACE	Land Development and Management Organizations								x	x	x	x			
COASTAL ZONE INTERFACE	Recreational Developers and Operators								x	x	x	x			

	Oceanographic User Community	Storm Surges (Wave)		Tsunami (Wave)		Bottom Characteristics		Salinity		Erosion		Wind		Clouds	
		Height	Diameter	Velocity	Direction	Size Distribution	Other	Surface	Subsurface	Extent	Amount	Velocity	Direction	Extent	Type
INDUSTRY	Petroleum Exploration, Drilling, Producing	x	x	x	x	x				x	x	x	x		
INDUSTRY	Ocean Mining and Exploration					x				x	x	x	x		
INDUSTRY	Shipping and Towing Optimum Routing	x	x	x	x							x	x		
SCIENTIFIC NON-GOVERN'T	Universities and Oceanographic Researchers	*	*	*	*	*						*	*	*	*
SCIENTIFIC NON-GOVERN'T	Fishing Commissions							*	*			x	x	x	x
SCIENTIFIC GOVERNMENT-NON-MILITARY	Bureau of Commercial Fisheries, Bureau of Sport Fisheries and Wild Life, State Fishing Agencies							*	*			x	x	x	x
SCIENTIFIC GOVERNMENT-NON-MILITARY	Environmental Science Services	x	x	x	x					x	x	x	x	x	x
SCIENTIFIC GOVERNMENT-NON-MILITARY	Bureau of Mines														
SCIENTIFIC GOVERNMENT-NON-MILITARY	U.S Coast Guard														
SCIENTIFIC GOVERNMENT-NON-MILITARY	National Aeronautics and Space Agency														
FISHING	Commercial Fishing Companies, Commercial Fishermen, Sport Fishermen					*		x				x	x	x	x
COASTAL ZONE INTERFACE	Port and Harbor Authorities					x				x	x	x	x		
COASTAL ZONE INTERFACE	Federal Water Quality Administration, State and Municipal Water Quality Agencies	x	x	x	x										
COASTAL ZONE INTERFACE	Land Conservation and Resource Agencies	x	x	x	x										
COASTAL ZONE INTERFACE	Land Development and Management Organizations	x	x	x	x	x				x	x	x	x	x	x
COASTAL ZONE INTERFACE	Recreational Developers and Operators	x	x	x	x	x				x	x	x	x	x	x

NOTES x - Explicit Requirements
* - Indicated Requirements

(1) Marine Organisms - Plant Life, Suspended Organisms, Red Tide, Chlorophyll, Bioluminescence, Fish Schools, Fish Oil

(2) Pollution - Particulate, Chemical, Oil, Thermal, Estuary, Effluents.

12 6 1 1 1 7 3 6

7 7 9 13 10 6 27

of organization with which the users are associated and whether the users are application oriented (Industry, Fishing) or research oriented (Scientific Government and Scientific Non-Government),with a special grouping for those users who were essentially land based and were interested only in the ocean as it interfaced with land (Coastal Zone Interface). Fishing was broken out as a separate entity rather than being placed as a subheading under Industry because of its uniqueness when compared with other Industry, (construction, petroleum.drilling, etc.) and also because it was taken to include sport fishing as well as commercial fishing. Subgroupings under Industry were chosen on the basis of types of industries while subgroupings under Scientific Government consisted of individual governmental agencies. The Scientific Non-Government group was divided into two sub-groups, Universities/Oceanographic Researchers and Fishing Commissions.

The appropriate selection of these general user categories in order to allow the proper relating of spacecraft missions and activities to user requirements is difficult. As may be seen in Table 2-1 and in later classifications the user categories chosen do not refer to strictly similar quantities nor are they completely independent in that there may be overlapping categories. That is, a user may in reality belong to more than one category. It is believed that without employing users categories which are so narrow that they are impossibly large in number some degree of overlap and dissimilarity in terms of the basis of user groups is inevitable.

In order to verify the breakdown of the user community and update user requirements obtained from the review of the SPOC provided reports it was decided to proceed with the development and distribution of questionnaires and the conduct of personal interviews. These aspects of the study have been previously discussed in Section 1 of the report. The reports provided by SPOC and personal contacts, as well as published oceanographic directories provided for a representative coverage of organizations and individuals with an interest in the oceans. Individuals and organizations contacted are listed in Appendices G through J.

On the basis of this additional information, a somewhat different user grouping was arrived at as illustrated in Table 2-2, Representative Users of Ocean Information. The six primary groups presented here and their associated sub-groups represent a refinement and modification of the user groupings of Table 2-1 and are used throughout the remainder of this report. The specific users listed in the table are, of course, only representative of much larger groups of users and are intended only as examples. As may be seen from Table 2-2, there continues to be apparent overlap with some individual users being named in more than one user group and with the six basic groups being somewhat dissimilar in nature. Despite the apparent problems, however, this method of user grouping was found to be advantageous in that one could consider information requirements, sensor requirements, and anticipated benefits reasonably effectively and efficiently.

The reasons for the chosen grouping of users can perhaps be completely understood only through careful reading of this entire report to see how the groups are used in relation to various aspects of satellite remote sensing. However, some degree of explanation of the rationale leading to this final user grouping is well worthwhile. For example, the industry users were grouped into the three separate classifications of marine transportation, fisheries and other industry because each relates to the ocean medium in a different way and in many respects requires different types of information. Moreover, the marine transportation and fisheries group are interested in data from most of the open ocean while the oil, mining, etc., sub-groups of the other industry group are interested almost exclusively in continental shelf areas. An exception to this is the recent developments in the mining of manganese nodules in non-continental shelf waters. Another characteristic of these three industrial sub-groups is that they tend to state their requirements in terms of information rather than data. These users would prefer that the raw data from the spacecraft be converted into the information that satisfies their requirements before it is presented to them. On the whole, these users have little knowledge or interest in spacecraft, spacecraft sensors, etc. As will be seen later in this report this makes identification of true needs of these groups in terms of data quantity, data accuracy, etc. difficult to assess.

Table 2-2 REPRESENTATIVE USERS OF OCEAN INFORMATION

- MARINE TRANSPORTATION AND ASSOCIATED ORGANIZATIONS
  - SHIPPING COMPANIES
    - UNITED FRUIT COMPANY
    - AMERICAN EXPORT ISBRANDSTEN LINES
    - SEA LAND INC
    - UNITED STATES LINES
  - WEATHER ROUTERS
    - PACIFIC WEATHER ANALYSIS CORP
    - LOUIS ALLEN ASSOCIATES
    - A H GLENN AND ASSOCIATES
  - MARITIME ADMINISTRATION
    - RESEARCH AND DEVELOPMENT
    - OPERATIONS
    - SHIP DESIGN
  - TOWING COMPANIES
    - MORAN
    - McALLISTER
    - PACIFIC TOWBOAT (DILLINGHAM)
  - PORT AND HARBOR AUTHORITIES
    - NEW YORK
    - SAN FRANCISCO
- FISHERIES
  - INDUSTRY
    - RALSTON PURINA
    - VAN CAMP SEA FOODS
    - OCEAN PROTEIN COMPANY
    - AMERICAN TUNABOAT ASSOCIATION
  - GOVERNMENT AGENCIES
    - BCF (MANY LABS)
    - U S FISH AND WILDLIFE SERVICE
    - STATE FISHING AGENCIES
  - INTERNATIONAL ORGANIZATIONS
    - INTERNATIONAL HALIBUT COMMISSION
    - INTERNATIONAL TROPICAL TUNA COMMISSION
    - NORTH PACIFIC FISHERIES COMMISSION
    - COMMISSION FOR THE NORTHWEST ATLANTIC FISHERIES
- OTHER INDUSTRY
  - MINERAL RECOVERY
    - GLOBAL MARINE
    - OCEAN SCIENCE AND ENGINEERING
    - DEEPSEA VENTURES, INC (TENNECO)
  - PETROLEUM EXPLOITATION
    - GULF OIL
    - STANDARD OIL
    - MANY OTHERS
  - CABLE LAYING
    - U S UNDERSEAS CABLE
    - AT&T
    - ITT
  - CONSTRUCTION
    - BROWN AND ROOT
    - HAWAIIAN DREDGING (DILLINGHAM)
  - LAND DEVELOPERS
    - COMMERCIAL
    - RECREATIONAL
- MAPPING AND HYDROGRAPHY
  - GOVERNMENT
    - COAST AND GEODETIC SURVEY
    - COAST GUARD
  - INDUSTRY
    - ALPINE GEOPHYSICAL ASSOCIATES, INC
    - OFFSHORE EXPLORATION, INC
    - WESTERN GEOPHYSICAL
    - OCEANOGRAPHIC SERVICES INC
- WEATHER FORECASTING AGENCIES
  - ESSA
    - NATIONAL ENVIRONMENTAL SATELLITE CENTER
    - WEATHER BUREAU
  - WEATHER ROUTERS
    - PACIFIC WEATHER ANALYSIS CORPORATION
    - LOUIS ALLEN ASSOCIATES
    - A H GLENN ASSOCIATES
- SCIENTIFIC/CULTURAL
  - GOVERNMENT AGENCIES
    - FWPCA
    - BCF
    - U S COAST GUARD
    - DEPARTMENT OF COMMERCE-ESSA MARAD
    - STATE AND REGIONAL ORGANIZATIONS
  - UNIVERSITIES/RESEARCH INSTITUTIONS
    - UNIVERSITY OF WASHINGTON
    - BATTELLE INSTITUTE
    - WOODS HOLE OCEANOGRAPHIC INSTITUTION
    - SCRIPPS INSTITUTE OF OCEANOGRAPHY
    - TEXAS A&M
    - MANY OTHERS
  - INDUSTRY
    - VAN CAMP SEAFOOD
    - DEEPSEA VENTURES, INC (TENNECO)
    - STANDARD OIL
  - COMMISSIONS
    - WORLD METEOROLOGICAL ORGANIZATION
    - PACIFIC MARINE FISHERIES
    - INTERNATIONAL TROPICAL TUNA COMMISSION

The two user groupings labeled Weather Forecasting Agencies and Mapping and Hydrography have the characteristic that the user is an intermediary who transforms the satellite derived data into information that the ultimate user can benefit from. In most cases these intermediary users can describe the data that they require but are not able to describe benefits since they are not the ultimate users.

The five user categories described above have in common the characteristic that each category of user has specific well defined problems to be solved that relate to specific needs. The last user category Scientific/Cultural covers those users who wish data concerning the oceans.because of a desire to better understand the ocean or some oceanic process without a clear idea as to precisely how this data will contribute to a specific practical problem. This is not to say that the Scientific/Cultural user may not have in mind the ultimate solution of a practical problem only that his desire for data is for essentially research purposes or simply to understand some characteristic of the ocean. The end item produced by users in this category will be research information and knowledge as opposed to an economic product or service. Two important characteristics of this type of users are: first, they usually require nearly raw data rather than information and second, it is not possible for them to clearly define the benefits to be provided by the data they request since they cannot foresee the extent of the practical applications of the research information and knowledge which they produce.

2.2 CLASSIFICATION OF INFORMATION NEEDS

This sub-section describes user information requirements in terms of phenomena to be observed and associated parameters to be measured. Section 3 quantifies requirements such as resolution, frequency and area of coverage.

Whereas the review of the documents provided by SPOC proved to be a fair source for identifying user groups it did not prove to be a

satisfactory means of identifying the requirements in terms of phenomena to be described and parameters to be measured. Not more than 20 instances were found within the literature provided where explicit requirements were defined. This is perhaps to be expected since many of the reports were studies of methods, or techniques, or hardware for remote sensing of the ocean and would not be expected to specifically call out user requirements.

In constructing Table 2-1, the ocean phenomena included are those which, in the estimation of CSC and SPOC personnel, after evaluation of remote sensor R and D, were judged to have a reasonable possibility of observation from space. With this as a base the various characteristics or parameters which are required to describe the phenomena were developed. Obviously, the measurement potential is not the same for each entry and some may be questionable. Section 5 discusses the current status of sensing each of these parameters. Again it will be seen, as was the case with the user groups, that the quantities classified as Phenomena are not all similar quantities and that there is overlap (e. g., color is considered a phenomenon while pollution, which can be detected using color information is also considered a phenomenon). Also it will be noted that the breakdown of phenomena as shown has practical advantages because it allows a correlation with both user requirements and sensor capabilities in an effective way.

Table 2-1 was compiled using information derived from the approximately 110 reports supplied by SPOC to CSC. The entries in the table represent either an explicit statement of requirements (an X) or a concensus by the CSC reviewers that within the reviewed reports there exists a rather firm indication that information in particular areas is required or desired (an *). As discussed above very few of these reports explicitely identified user requirements. The one report that contained a comprehensive listing was "Oceanography and Meteorology", produced by Douglas Aircraft Company (44). Many of the requirements depicted in Table 2-1 were obtained from this document. Whenever possible inputs were confirmed by other sources. It can be seen from

Table 2-1 that a significant number of blank spaces appear. This is not meant to imply that no information is needed in these areas by the users but only that the requirements were not identified in the limited information sources provided.

It was obvious that if a more complete and relevant chart was to be developed, additional information sources had to be utilized. It was thus decided to proceed with the survey of the various entities within the oceanographic user community to update and validate the impressions formed by the document review. This was accomplished through the prepared questionnaires and personal interviews mentioned previously as well as the review of additional documents.

Table 2-3 graphically illustrates the results of CSC's survey efforts undertaken to verify and update information obtained from the review of SPOC reports. Those questionnaires mailed to instrument developers are not included in these totals. The totals of columns 2 and 3 are somewhat misleading as many of the inquiries and interviews provided information in more than one category, however, for consistency they were only placed into the category that appeared most applicable. The totals for Mapping and Hydrography are necessarily low since only a few groups are active in this endeavor. Primarily the USC & GS and the Navy along with a few commercial and research organizations.

One user category in which one would expect a greater response is marine transportation, however, a number of those individuals contacted for interviews stated that they were interested only in the most accurate sea state information possible and felt that an interview was not called for. The largest number of responses, as was expected, were in the scientific area. This results primarily from the fact that these individuals and organizations are responsible for developing new ways of acquiring ocean data and utilizing such data for obtaining a better understanding of the marine environment.

The total number of questionnaires distributed to users was 252 and the total number of useful returns was 66 for a response rate of

TABLE 2-3

RESULTS OF CSC'S SURVEY

User Category	Questionnaires Distributed	Questionnaires Returned	Interviews Conducted	Totals
Marine Transportation	38	6	3	9
Fisheries	70	8	10	18
Other Industry	82	27	4	31
Mapping and Hydrography	12	2	2	4
Weather Forecasting Agencies	14	6	3	9
Scientific/Cultural	36	17	33	50
TOTALS*	252	66	55	121

*Totals do not include questionnaires sent to instrument developers

22%. We feel that this response rate is about average for this type of survey. However, a number of these were not completely filled in, thus making them of little use. Lists of those individuals and organizations querried are found in Appendices G and H. Appendix I lists the 59 instrument developers who were querried concerning sensor state of the art. Appendix J includes those individuals interviewed in person. The information obtained in these questionnaires was also of significant use in Section 3 for documenting detailed data requirements and in Section 5 for documenting the status of remote sensors.

As may be seen the questionnaire response rate was low. However, personal contacts were extended until there was assurance that responses related to each user group were obtained.

As a result of the questionnaires and interviews and the review of additional documents such as references 4 and 132 a new user requirements matrix was developed based upon the revised user classification categories presented in Table 2-2. The results are presented in Table 2-4.

Table 2-4 demonstrates those types of oceanographic information which might be of interest to different classes of users and which are potentially measurable using remote sensing techniques. Because of the broad spectrum of information sources on which the table is based almost all of the significant user groups and their information needs are identified. A general discussion of these needs is presented in the remainder of this section. The discussion is arranged in terms of the phenomena and parameters to be sensed. The three categories of Erosion, Wind, and Clouds are not discussed here or through the remainder of this report since these were not considered to be truly oceanographic parameters. The discussions of requirements in this section are carried out in general terms. Details in terms of geographic coverage, frequency of coverage, resolution etc. are presented in Section 3.

2.3 DISCUSSION OF INFORMATION NEEDS

In the previous Subsection the needs of the various groups have been tabulated by phenomena of interest. This Subsection will discuss the basis of the need for observations of the phenomena of interest.

2.3.1 Marine Organisms

Oceanographic knowledge assists in increasing the harvest of the sea in five ways: (1) location of highly productive fishing areas, (2) identification and location of promising unutilized fishery resources, (3) providing the fisherman information which he can use to improve his tactical scouting and catching operations, (4) forecasting space and time variations in the abundance and catchability of fish populations, and (5) providing the scientific basis of rational management of the heavily exploited fisheries.

Few specific requirements for this type of assistance have been documented, but Dr. Wilbur B. Schaefer, Director, Institute of Marine Resources, University of California has expressed for the fisheries industry a statement of their needs in the five areas above. Essentially

TABLE 2-4
THE OCEANOGRAPHIC USER COMMUNITY
AND THEIR AREAS OF INTEREST

OCEANOGRAPHIC USER COMMUNITY	PHENOMENA / PARAMETERS	Marine Organisms (1)			Pollution (2)					Water Temperature		Sea State (Wave)			Currents (Horizontal, Vertical)			Sea Ice			Icebergs		Heat Energy Exchange	Color	Depth		Tides		Geoid	Mean Sea Level	Sea Slope	Storm Surges (Wave)		Tsunami (Wave)		Bottom Characteristics		Salinity		Erosion		Wind		Clouds		
		Extent	Type	Amount	Extent	Quantity	Velocity	Direction	Content	Surface	Subsurface	Height	Length	Direction	Velocity	Direction	Extent	Extent	Thickness	Type	Velocity	Direction	Temperature	Color	Bathymetry	Bottom Contour	Height	Period	Sea Surface Geometry	Sea Surface Geometry	Angle of Slope	Height	Diameter	Velocity	Direction	Size Distribution	Other	Surface	Subsurface	Extent	Amount	Velocity	Direction	Extent	Type	
MARINE TRANSPORTATION AND ASSOCIATED ORGANIZATIONS	Shipping Companies											X	X	X	X	X	X	X	X	X	X	X			X	X	X	X				X	X	X	X							X	X			[illegible]
	Weather Routers									X		X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X				X	X	X	X							X	X	X	X	12
	Maritime Administration				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X						X	X									X	X			
	Towing Companies											X	X	X	X	X	X	X	X	X	X	X			X	X	X	X				X	X	X	X							X	X			9
	Port and Harbor Authorities				X	X	X	X	X			X	X	X	X	X	X	X	X	X					X	X	X	X				X	X	X	X	X				X	X	X	X			11
FISHERIES	Industry	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X							X	X	X						X	X			X		X	X			X	X	X	X	[illegible]
	Government Agencies	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X							X	X							X	X					X	X			X	X	X	X	[illegible]
	International Organizations	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X							X	X							X	X					X	X			X	X	X	X	11
OTHER INDUSTRY	Mineral Recovery				X	X	X	X	X			X	X	X	X	X	X	X	X		X	X			X	X						X	X	X	X	X				X	X	X	X			11
	Petroleum Exploitation				X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X			X	X	X	X				X	X	X	X	X				X	X	X	X			[illegible]
	Cable Laying											X	X	X	X	X	X								X	X	X	X				X	X			X		X				X	X			[illegible]
	Construction											X	X	X	X	X	X	X	X	X					X	X	X	X				X	X			X				X	X	X	X			[illegible]
	Land Developers	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					X	X	X	X				X	X	X	X	X				X	X	X	X	X	X	14
MAPPING AND HYDROGRAPHY	Government Agencies																								X	X										X										2
	Industry																								X	X										X										2
WEATHER FORECASTING AGENCY	ESSA				X	X	X	X		X	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	19
SCIENTIFIC/CULTURAL	Government Agencies	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	21
	Universities and Research Institutions	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	21
	Industry	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X										X	X			X	X	X	X			[illegible]
	Commissions	X	X	X	X	X	X	X	X	X	X				X	X	X							X														X	X							
		8			13					11		17			18			13			8		4	8	19		11		3	3	3	16		[illegible]		13		8		9		17		8		

(1) Marine Organisms - Plant Life, Suspended Organisms, Red Tide, Chlorophyll, Bioluminescence, Fish Schools, Fish Oil

(2) Pollution - Particulate, Chemical, Oil, Thermal, Estuary, Effluents

he calls for an extension and expansion of systematic scientific observations which may lead to the identification of important latent resources or revealing fish behavior in relation to catching operations. He also indicates a need for improved forecasts of fishing locations and expected catches.

To make such forecasts we need to have useful estimates of the magnitude of the exploitable fish populations and (of most importance to space applications), understanding of the distribution and behavior of the fish in relation to measurable properties of the ocean such as temperature, salinity, depth of mixed layer strength of currents, and upwelling. Relatively simple prediction models have been conceived which are further described in Section 4.2.2. Information required for such models would relate (as Dr. Chapman suggests) distribution of fish resources to certain physical characteristics of the environment and the availability of food. The model conceived would require the following parameters as input:

Sea Surface Temperature
Surface Currents
Color of the Water
Surface Winds
Chlorophyll Content
Salinity

The model would seek to identify some effect or combination of effects of these parameters which if correctly interpreted will provide a greater possibility of locating economic concentrations of fish (96).

Sea surface temperature is one of the most frequently discussed parameters, along with nutrients, that is associated with the presence and abundance of fish and is presently predicted for the eastern Pacific. Even though this program includes only a modest portion of the world ocean and the input data coverage is sparse, the program has been of some significant benefit to the tuna industry as partially evidenced by the continued participation of individual fishermen. Improvement due to a uniform, synoptic and comprehensive data input such as is possible from space is obvious. In summary, the most important improvement fisheries could expect from satellites would be in providing better data for construction of predictive models. Of secondary importance would be the direct detection of fish.

2.3.2 Pollution

Requirements for pollution information include measurements of the various organic, inorganic, and biological materials that are important in water quality control. These data are essential to federal, state and municipal agencies in determining the existing quality of marine waters, in establishing procedures to maintain or improve these levels, and in designing and implementing monitoring and enforcement programs. These data are also of importance to municipal sanitation agencies, industrial dischargers, oil companies, fish and game agencies, and recreation and conservation groups.

The greatest density of data is required from coastal areas such as bays, estuaries, harbors, marinas, and the surf zone; and offshore data around oil drilling platforms and river outflows (20). At the present time pollution data are collected on a routine basis only for purposes of monitoring sewer outfalls, or in areas where special problems exist. The Federal Water Quality Administration (FWQA) recently required state agencies to establish water quality criteria for marine waters (which are defined as interstate waters in most cases), and a no-degradation policy has been firmly stated (82).

Data products required by state agencies are the following: water quality; related biological (ecological) information; current, upwelling, and climatic data relating to dispersion and assimilation of wastes; location of outfalls and descriptions of past and present effluent volumes and characteristics; description of other sources of pollutants, including industrial operations, shipping, boating, flood runoff, etc.; and present water quality objectives and federal, state, and local regulations designed to meet these objectives.

With the exception of specific outfall monitoring reports, marine water quality and pollution data reports produced at the present time are issued on an irregular basis. They are generally highly specialized and have very limited application and usage. There is a need for the collection and analysis of basic data on a much broader basis.

Since very little is known about the factors which determine marine water quality, particularly in terms of the biological consequences of changes in the marine environment, the need for additional data is extremely important.

There is increasing indication that even the open oceans are becoming polluted. It is important to identify both the nature and extent of the pollution as well as to identify the sources of pollution.

2.3.3 Sea-Surface Temperature

Sea-surface temperature is the most frequently measured ocean state variable. In spite of marked variations in observational methods and instruments, it is the logical base to which the subsurface thermal structure is related. The majority of ship observations are of cooling water injection intake or bucket temperatures. Bathythermograph observations are sparse, but gradually increasing in number. Airborne radiation thermometers (ART) are also being used at an increasing rate (90).

Charts indicating the horizontal distribution of sea surface temperatures are produced routinely by a number of organizations on a daily to monthly basis and cover regions ranging from local operating and fishing areas to total global coverage. Such charts are used for both forecasting and historical data studies.

Several thousand ship observations of sea-surface temperature from the Northern Hemisphere are available each day. Distribution of observations is not homogeneous, however, and most observations are made along major shipping lanes. Data are transmitted by ships in their routine weather messages and data accuracy is not high. Information, even from the Northern Hemisphere is not sufficiently dense to resolve many features of importance, and the Southern Hemisphere is essentially unsampled. The average density of data for the Western North Atlantic on an annual basis is about one surface temperature data point per day per 26,000 square kilometers (50). On a global basis, the annual average is about 1/5 of that value. Regions of severe weather tend to be undersampled, although the presence of clouds does not interfere (as it does in the case of airborne infrared measurements).

Sea surface temperature charts primarily based on ship observations are routinely prepared and published by such organizations as the U.S. Naval Oceanographic Office, the Fleet Numerical Weather Central, and the Japanese Meteorological Agency.

Groups that are presently relying on ART data to an ever increasing extent include, for example, the U.S. Coast Guard which acquires temperature data over the North Atlantic and Pacific coastal areas on an operational basis. Such data have been also recently used by the Bureau of Sport Fisheries and Wildlife (BSFW) to prepare temperature charts along the Atlantic and Pacific coasts. Sea surface temperature data are also acquired over the North Atlantic by the ASWEPS program for use by the Naval Weather Service to prepare sea surface and layer depth temperature charts. Data are transmitted to the Navy fleet on a daily basis and to other interested, scientific, commercial and military operations.

Temperature is one of the more easily determined environmental factors, and its correlation to fish population is readily demonstrated (see Section 4.2). However, in view of the multiple uses of sea surface temperature information, requirements for accuracy, scale, and frequency of observation range from 0.01°C, a few meters, and minutes, to 1°C, tens of kilometers, and intervals of months. In terms of a space goal, an absolute accuracy of ±1°C has been suggested (77). At the present time, an accuracy of 0.01°C is not believed to be feasible from space (77), however, such resolutions have been approached using an airborne IR radiometer developed by Scripps for heat flow studies (64). Results of this study are discussed in Section 4.9.

If all-weather space measurements are feasible (passive microwave sensing), a direct synoptic analysis of sea-surface temperature could be produced. If cloud-free areas only can be observed, it might be necessary to maintain surface-temperature distribution as a continuing analysis, appropriately updated on a suitable computational grid as new information is received. For more complete areal coverage, observational data could be extrapolated into cloudy regions with the assistance of other known meteorological and oceanographic parameters, including surface observations from ships and buoys.

The present average data base samples 6% of the ocean. It is apparent that the single greatest improvement that can be made in the existing system is to increase the data input. Present data needs also include broader geographical coverage, especially in the Southern Hemisphere; more closely spaced contour intervals (at least 1°C) are required for historical SST charts;

and more timely preparation and distribution of the charts. At the present time, with the exception of the daily charts used for forecasting, time lags between observation and final dissemination of the products may range as long as months.

Sea surface temperature information may also be useful for establishing the boundary of ocean currents and is in this respect of interest to marine transportation users for ship routing as well as the scientific community which is interested in understanding ocean circulation.

2.3.4 Sea-State/Wind

In view of the recent rapid acceleration in activity and interest in the marine area, many of the needs for sea-state and/or wind are not being met to the satisfaction of the user communities (132). Thus, as discussed below, new techniques and programs are required to satisfy some of these unfulfilled needs.

- Wave Height Forecasts

This group of products includes wind-wave prognoses, swell prognoses, and combined wave forecasts for 24-hour and 36-hour periods. The predictions are based solely on wind fields computed from surface pressure. If this prognosis is obviously in error, the wave heights should be used with caution. These predictions are issued in the form of areal charts for the North Atlantic and North Pacific Oceans, containing contour lines of forecast wave heights at three-foot intervals and values of maximum wave height centers. Twenty-four charts per day are transmitted, 10 to each Atlantic, Gulf of Mexico, and Pacific seaboard station, and four combined wave charts to the Gulf of Alaska stations. To increase the availability of these forecasts, ESSA plans to establish a civilian facsimile and communication network which will be implemented to provide transmission on a firm schedule.

It appears at this time that the use of various spaceborne all weather radar systems could provide significant information on wave heights. This information is essential for optimum ship routing of naval and merchant vessels.

- Coastal Weather and Wave Forecasts

These forecasts indicate surface weather and sea conditions and upper air conditions for periods up to 36 hours after the previous synoptic time for all

U.S. coastal areas out to 80 kilometers at sea. They are produced four times daily by 18 area forecast centers. Warnings are issued for expected hazardous conditions as required.

Coastal weather and wave forecasts are of major importance to recreational boatmen and for short-term planning of salvage and submersible vehicle operations. Adverse weather conditions can limit or prevent these activities. Both commercial and sport fishing vessels require these forecasts for day-to-day planning and operations in order to maximize catch and avoid hazardous conditions. A common complaint from present users is that forecasts are made for a large area and are not sufficiently localized to be of use for a specific oil drilling rig, recreational boatmen or for marine coastal engineering operations.

The use of high resolution sensors being proposed for spaceflight in conjunction with other surface and airborne sensors may be able to improve significantly the data now being distributed to users operating in the coastal area.

- High Seas Weather Forecasts

These forecasts indicate surface weather for periods up to 36 hours for oceanic areas extending from 80 kilometers offshore to limits defined by the World Meteorological Organization (WMO) International Convention. They are issued by three area forecast centers (and by Fleet Weather Centrals) four times daily. Bulletins contain forecasts and warnings.

These forecasts are utilized directly in navigation and routing of naval and merchant ships including sea-going tugboat operations. Since these forecasts provide a means of predicting sea state and fetch, they are also an essential input for surf condition forecasts.

Shipping companies state that these forecasts are not available in some locations, that the facsimile charts received are difficult to read because of distortion, and that there is not a close adherence to transmission schedules. Of the two commercial and five Navy radio stations which broadcast marine weather information for the Pacific Ocean and South China Sea, none transmits more than 480 kilometers seaward north of 8° north latitude. Facsimile transmissions are made on a direct beam from San Francisco to Melbourne, Australia, and from Honolulu to Wake and Kwajelein Islands for use by Weather Bureau units

at these locations. Forecasters state that their forecasts would improve if an increased number of equally spaced synoptic reports (500-800 kilometers) in their area of responsibility were available. They also reveal that hemispheric products from the National Meteorological Center (NMC) are sometimes received after the beginning of their forecast cycle for the same synoptic period.

The acquisition of sea-state information using spaceborne instruments should provide not only more frequent information than now obtained but also wider area coverage and coverage of remote areas. This data combined with that provided by other data acquisition systems could go a long way towards providing the information required by many users.

2.3.5 Currents

For utilization in ship operations planning, navigation, search and rescue planning and operations, and fish locating, an increase in the level of detail of current information for the continental shelf is needed. An additional unfulfilled need is for increased accuracy. Over 98% of the surface current data consists of set and drift observations made by Navy and merchant ships. These observations reflect the average surface current over a distance of 80 to 650 kilometers and have a highly questionable accuracy because of variations in navigation accuracy, steering and frequency of speed and course changes (132).

Tidal current tables are published for a number of the waterways on the Atlantic Coast of North America and on the Pacific Coasts of North America and Asia. These tables include predictions of the time of slack water, the times and speed of maximum flood and ebb currents, and methods for obtaining predictions for various locations. These products are used for navigation purposes and also have value in coastal operations and water pollution control activities. There exists a minor need for greater detail, but the products are satisfactory for most purposes. Port and harbor authorities are interested in the flow which not only affects harbor design but also deposits silt and sediment, which creates a need for dredging. Their requirements for information therefore are somewhat more stringent.

Petroleum and other industries engaged in exploration for and recovery of offshore resources require current information in design of off-

shore installations, planning their operations, and dispersion of sediment resulting from mining. In areas such as Cook Inlet, Alaska, currents must be considered when designing and placing the platforms and in locating and orienting mooring facilities. The existing level of detail in current information is not considered adequate for the purpose.

Currents flow other than in the horizontal plane and while practically all elements of the user community have requirements for information on horizontal water motion, the interest in upwelling and downwelling is restricted to a much smaller community, predominantly the fishing industry to whom associated changes in temperature, salinity and nutrient levels affect the habitats of fish. Thus, although representing a smaller community, the requirements of the fisherman are real in this area.

It is expected that the charting of currents from space on a global and quasi-synoptic basis will also provide an input to sea-air interaction studies, long-range weather prediction and heat budget and climate research.

2.3.6 Sea Ice

Sea ice forecasts are issued as large-scale charts which cover specific areas such as Baffin Bay and the coast of Alaska. They indicate the nature, extent, and concentration of sea ice cover. Iceberg concentrations and distributions may also be indicated. These forecasts are transmitted by radio, teletype, and facsimile to all vessels, civilian and military, operating in ice areas. Sea ice forecasts are an essential product for ship routing and operations planning for merchant shipping in areas where ports and shipping lanes are subject to icing. They are also essential in the planning of naval logistics operations in support of polar stations and bases, and in the planning of naval submarine operations in polar waters. Industrial operations are increasingly concerned with sea ice in view of the growing promise of economic return through development of mineral and petroleum reserves in the arctic.

Forecasts of ice conditions on the Great Lakes and the St. Lawrence Seaway are produced by ESSA as well as by the Canadian Government. The effectiveness of merchant shipping operations and routing in the Great Lakes and inland waterways is directly dependent on the timeliness and accuracy of these forecasts.

Present forecasts have about a two-week uncertainty, whereas accuracy within one day is desired. Five-day warnings of port closing and daily ice survey bulletins following the initial opening of ports and during the final days before freeze-up are needed. Ice survey bulletins should contain ice coverage, ice thickness and ice type data (132).

Currently available ice atlases consist of maps indicating the monthly average and extreme of ice coverage, thickness, and type. Also included are the mean range of ice freeze-up and breakup dates. Worldwide coverage is available only at small scales. Larger scales and increases in geographic coverage, especially for continental shelf areas and the Great Lakes, are needed for planning ship operations, environmental predictions, offshore oil operations, offshore and shoreline structure design, and vessel navigation.

From the point of view of basic research there is need for considerably more detailed information on variations in polar ocean pack ice cover. This need derives in part from the opinion of some experts who consider the intense heat sink effects of temporarily open water areas (large polynyas) to have a major bearing on the periodic outbursts of cold polar air which substantially affects northern hemisphere weather.

2.3.7 Icebergs

Undetected icebergs represent a definite hazard to shipping, although it has been many years since a disaster at sea has been directly related to collision with an iceberg. Generally, this attests to the success of the International Ice Patrol in achieving its mission. The availability of radar to surface shipping would seem to eliminate the need for the surveillance provided by the Ice Patrol, but efforts by both the USSR and United States shipping authorities to use radar for iceberg detection aboard surface ships have met with limited success (96). The reason is that icebergs are poor radar targets because they are highly absorbent to microwaves. The smaller bergs, known as growlers, are even more dangerous to navigation as they are virtually undetectable by radar.

However, the very property which makes the iceberg an unattractive target to a radar, its absorptivity makes it an excellent one for a microwave radiometer. The iceberg shows up nominally 100° hotter than the sea, thus justifying a closer look at this particular space application.

The U.S. Coast Guard has commented in interview on the limited coverage of the broad ocean area provided by ships and/or aircraft in iceberg detection as well as the fact that both are weather limited. They presently provide coverage on the Grand Banks and in the Labrador Sea and although not pressed for coverage in new areas, express a need for more frequent and complete coverage in the areas of responsibility.

The experience gained through nearly ten years of studying satellite ice imagery provides the basis for specifying further spacecraft experimentation in this field. In particular, improved resolution and contrast over that already achieved with TIROS narrow angle cameras or with Nimbus AVCS photography is needed. Aerial iceberg patrols could be substantially reduced, possibly eliminated, with ground resolution of 8 meters (19). Requirements for tactical aircraft support of ship operations could also be significantly reduced with this same resolution. With a ground resolution of 30 to 300 meters, the necessity of conducting long-range reconnaissance flights to obtain ice information for forecasting purposes, or to detect and measure ocean currents by tracking large ice flows or ice islands, could be largely eliminated.

2.3.8 Heat/Energy Exchange

Many aspects of research in air-sea interaction are now beginning to receive attention. However, much more remains to be done. The most obvious interchanges between sea and atmosphere are those of water, heat and momentum. Careful measurements of radiation, temperature gradients in the lower atmosphere and upper layers of the sea, precipitation and humidity in the air, salinity at the air surface, and the formulation and breakup of sea ice, can lead to understanding of these major exchanges (20).

There are, however, many other types of exchanges between oceans and atmosphere, some exceedingly subtle in their requirements for observations, all of which need to be studied in detail.

Energy is transferred from wind to ocean as kinetic energy of waves and currents; severe storms may greatly modify the ocean layers over which they pass, mixing the surface layers to produce profound temperature and salinity changes. Solid particles are exchanged between the sea surface and the atmosphere as are gases.

A broad attack on the theoretical and technological problems of providing adequate worldwide meteorological information is now being planned and coordinated by the World Meteorological Organization under the designation of the World Weather Program. Critical importance is attached to the understanding of the interaction between ocean and atmosphere, on the one hand for predicting the state of the oceans and on the other hand for predicting the state of the atmosphere.

At present, numerical models and other methods for short- and long-range prediction are rapidly advancing to the point where they can directly incorporate the effect of heat sources and sinks. For the atmosphere the primary external heat sources are at the interface with the underlying oceans and ground. The energy exchange at the ocean-air interface is one of the governing factors of the general circulation.

Synoptic data on the surface temperature of the globe as required by the World Weather Watch are, at this time, sparse or missing entirely over many oceanic areas. There is hope now, although not a well-expressed requirement, that technological problems can be overcome to obtain these measurements from spacecraft.

The precise measurement of absolute surface temperature from space is more difficult than that of relative temperature differences because of the radioactive contributions of the atmosphere itself. To eliminate or correct for these contributions, a very narrow atmospheric spectral window must be used which in turn implies conflicting requirements in available energy and desired ground resolution (65).

2.3.9 Bathymetry

The application of remote sensing techniques to hydrographic charting will probably be confined to shallow water effects, such as the "doubtful shoal" problem (19). However, ESSA is considering the application of navigation satellites to locate positions of ships as they station themselves over the 200 meter bathymetric contour, for the purpose of defining and locating the edge of the continental shelf to a better degree of reliability than is normally practiced. The requirement for added precision stems from the addition of political boundaries to continental shelf maps and the establishment of state seaward boundaries on submerged land parallel to the shoreline (U.S. Congress, 1953) as well as the extension of state and national dry land boundaries into the sea (19).

A worldwide problem is the detection and charting of doubtful and uncharted shoals. Since numerous offshore hazards to marine navigation are reported annually, these potential dangers must be shown on all pertinent nautical charts until either specifically disproved or properly identified by accepted survey methods. Such methods are not always practical because of high search costs. The problem was so acute that as early as 1947 member nations (of which the United States is one) of the International Hydrographic Bureau (IHB) passed a resolution (146, 147) requesting that it be given top priority for immediate solution. It was estimated that by using only surface ships to investigate possible shoals, it would require 20 years of concerted effort by all nations to solve it. Since this problem encompasses all oceanic areas, a large area survey technique, such as from space, is needed to detect shoals and permit comparison of data obtained from conventional hydrographic charts. Ships or aircraft could then be dispatched, if necessary to specified locations for more detailed studies.

In addition to detecting isolated shoals in the deep sea and shoal water close to land, information is needed about partially or totally submerged stationary or floating objects (derelicts) which could be hazardous to ship operations. Image sensors which provide a coarse resolution could be used to detect most natural shoal features of vital interest, but resolutions should be better than 30 meters in order to detect bars and reefs. To satisfactorily identify "derelicts", remote image sensors should have very high resolutions.

It will be necessary to cover all the world oceans at least once to be sure all possible shoal areas have been detected. There will also be a need to monitor some oceanic areas at regular intervals to detect relatively rapid morphological changes. This coverage could probably be provided best from a polar-orbiting spacecraft.

Improved hydrographic charting is required for other applications such as tsunami forecasting and fishery research. Additionally, needs have been cited for larger scale charting than is now available in many areas of the world for waste disposal management, estuarine flushing forecasting, offshore oil and mining operations, surf forecasting, submersible operations and salvage operations (132).

2.3.10 Sea-Surface Topography

The geocentric radius to the surface of the land and sea is a changing quantity at each point of the Earth. Tidal forces, wind stress, and barometric pressure constantly remold the sea surface. These changes can be progressive, cyclic, or intermittent, but each has an explanation and significance in furthering understanding of physical processes at work within the oceans and atmosphere (66).

A satellite altimeter in near-polar orbit would provide a coarse-grained topographic map of the sea-surface every 12 hours. A time-series of such maps would provide evidence of change in the oceans that may easily reveal unexpected phenomena in the sea for scientific investigation.

Of fundamental importance to physical oceanography is the measurement of the difference between the topography of the physical sea surface and that of the geoid. Given the geopotential of the sea surface and knowing from ship observations the internal distribution of water density, it would then be possible to compute the dynamic topography of all isobaric surfaces and the values of the global geostrophic transport of mass and heat by ocean currents at all depths.

Thus, through determination of geoidal undulations over the broad extent of the oceans, it may be possible to develop models for ocean circulation that could lead to predictions of regions of upwelling and convergence, thus aiding the fishing industry.

Oceans are a long-term indicator of climatic anomalies and, in turn, once the oceans have established an oceanographic anomaly, the feedback to the atmosphere produces persistent climatic anomalies. Thus if the geoid is determined by space applications to sufficient precision, the year-to-year departures of the sea surface from the geoid will have important implications in long-term weather prediction. For example, if the Gulf Stream currents were found to be 20% stronger than average, this would imply anomalous weather conditions in the Iceland, Great Britain and Scandinavian regions.

The use of the satellite altimeter to delineate storm surges and possibly tsunamis and the use of satellite communications to transmit seismic and tidal data obviously contribute to protection against certain environmental hazards.

SECTION 3

COMPILATION OF USER OCEANOGRAPHIC REQUIREMENTS

Section 2 summarized oceanographic user requirements in terms of the oceanographic phenomena and parameters to be measured and associated these with the users who had the requirements. The objective of this section of the report is to detail the oceanographic requirements of each user group so as to provide insight as to type of spacecraft missions required, requirements placed on sensors, and format and density of user data requirements. This information will then be used in conjunction with the results of Sections 4 and 5 to place in context past SPOC efforts and to identify future profitable directions.

A number of studies have been conducted in the past, with part of their objective being to determine user requirements for a spaceborne sensor system (36, 44). These compilations of user requirements have always been received with mixed emotions, probably because of the lack of detail presented and because of the limited number of basic users (shippers, fishermen, drilling companies, etc.) that were contacted.

A second type of analysis that has been undertaken and received even wider attention are the studies completed by the Travelers Research Center (4) for the National Data Buoy System (NDBS) and by the System Development Corporation (SDC) for a National Data Program for the Marine Environment (132). The former study addressed itself primarily to the determination of oceanographic user requirements that might be satisfied by the NDBS. This study was exhaustive in that it covered many potential users and also included a number of analyses of the collected information. Incorporating their results into a requirements survey for a space system proved difficult because the inherent capabilities of the two systems are vastly different. For example, buoys are capable of providing very high resolution point sources of surface and subsurface data, while space systems will provide wide synoptic viewing of primarily surface phenomena on a global scale. Hence, when attempting to utilize the NDBS requirements survey to obtain

user requirements for consideration for satellite acquisition, the inherent capabilities of each system were kept in mind so as not to necessarily complicate the study with inputs that are either impractical or theoretically infeasible.

The SDC study covered the total data program for the marine environment and touched on most aspects of oceanographic requirements from ocean engineering through marine resources development. Thus they addressed user requirements in a general manner which proved to be a good list for comparison with our results. In those cases where similar type inputs were being solicited, the resultant requirements corresponded rather well. Both of these studies provided general background information of restricted but worthwhile use in the present study.

The compilation of user requirements developed under this study are presented in Tables 3-1 through 3-6. This compendium provided the necessary information for determining the current capability of remote sensing techniques, either from aircraft or spacecraft, to provide data to satisfy the stated user requirements. Results of this task are delineated in Section 5 - Status of Remote Sensing of Oceanographic Parameters. The second objective of this compilation was to provide basic information in a format that would be appropriate for analyses to determine the data acquisition system best qualified for acquiring the data. This latter analysis is beyond the scope of the contract.

The information sources used in preparing Tables 3-1 through 3-6 included, in addition to previous requirement summaries, the results of the literature review, and of the questionnaires and interviews conducted. Only the requirements of the U. S. user communities were solicited and compiled into this report.

As may be seen by Appendix G, a special effort was made to reach the ultimate industrial users of oceanographic information such as fisherman, marine transporters, and members of the offshore oil and mineral industry. The information on the response rate has been presented in Table 2-3. Once again the difficulty of obtaining direct requirement inputs from ultimate users was encountered. This difficulty is one that CSC has commonly experienced in attempting to define requirements. Most potential ultimate users of the

data to be produced by spacecraft remote sensing know only what their ultimate requirements for information are. One cannot expect these users to be able to translate their information requirements into spacecraft data sensing requirements. Nevertheless their inputs are extremely valuable. For one thing, the ultimate user is the best source of information as to the optimum form for the final information format. What must be done to obtain additional information is to begin with the ultimate user's information requirements and proceed through a logical chain. Taking the users information requirements researchers must be approached to determine the phenomena and parameters which must be determined to provide the desired user information. At this step it is well to consult the full gambit of researchers, the majority of which will not be space oriented. Finally, the results obtained from the non-space oriented researchers must be reviewed by individuals who are familiar with both the science in question and space sensing capabilities. This final step has been found to be necessary in all past attempts by CSC to translate user information requirements to spacecraft data sensing requirements. The need for this step arises because the non-space oriented scientist is often unaware of the radical difference in the nature of space sensed data and surface acquired data and is often unable to translate surface gathered data requirements into satellite sensed data requirements.

The data presented in Tables 3-1 through 3-6 represents the final compilation of satellite data requirements based on a synthesis of all available inputs. The final synthesis was carried out by study personnel having both oceanographic and remote sensing experience and represent the conclusions of these personnel based on the available data. Those stated requirements that substantially deviated from the majority of the requirements which were synthesized to produce the tables are indicated in the tables under the heading "Comments".

Tables 3-1 through 3-6 are divided with one table for each of the six user groups, previously identified in Figure 2-2. Within each group, those particular ocean features of which knowledge is required to provide the pertinent information to the user are listed. In turn these are subdivided according to the extent of the geographical area of interest. These sub-

divisions are global, regional and local - and for the purpose of this compilation are defined below.

GLOBAL - Global as the name implies includes all of the ocean areas of the world including the continuously frozen marine areas of the Arctic and Antarctic. Two subcategories may be used as appropriate.

World's coastal zones to 200 m isobath,

World's deep ocean area.

REGIONAL - A region is typically defined as a broad oceanic area such as the North Atlantic Ocean, the Atlantic Coast from Florida to Canada, the Great Lakes, and the Arctic or Antarctic areas. Its extent is less than global and greater than local and when it includes coastal areas will be so stated, as - Regional (coastal). The North Atlantic region includes the coastal zone and deep ocean area. A region may be a notable large-scale phenomenon such as the Gulf Stream or the Mid-Atlantic Ridge.

LOCAL - A local area is an ocean area of limited dimensions where certain oceanographic data are required. A local area may border on the coast, for example, Monterey Bay, where data are required in connection with a pollution study, or it may be in the open ocean where data are required in connection with petroleum exploration, i. e., a drilling site. A local area is not defined by size. It differs from regional areas in that it has explicit boundaries which are set by the interests of the individual(s) requiring the data on the feature itself. A river estuary of any size would be a local area by this definition.

Other specifications that are identified in these tables includes frequency with which information is required, the optimum presentation of information, data points required, and resolutions required.

The compilation of user requirements in this format should expedite requirements analyses for determining those needs that are most applicable for satisfaction by space and/or airborne acquisition. Preliminary deductions that are obvious after a surficial study of Tables 3-1 through 3-6 indicate that many requirements, i. e., frequency, resolution, and number of data points do in fact change with geographic area. For example, these require-

ments are most stringent for local areas which are usually near-in coastal areas. Also to be noted are the indicated spread of some of the numbers. This spread indicates that numeric statements of requirements often cannot be made in terms of a single number which, if achieved, will completely fulfill a user's needs, with there being no advantage to the user if the number is not achieved. An example of this might be in the case of sea surface temperature information. Certain fisheries have specified an information input frequency requirement of 1-4 times a day. It is obvious that a fairly high resolution space system in a polar orbit will not pass over a given lower latitude area four times in a day, and thus to satisfy this requirement, one would need a number of satellites simultaneously in orbit. But even one sample a day would provide useful information to the fishery in question. In other words, for any part of the spread that can be met, a certain percentage of the user's requirements will also be met. It is generally believed that often 100 percent of any user requirement could not, in fact, be satisfied by the exclusive use of a single data acquisition system, and that a combination of surface, airborne and spaceborne sensors will be required in most cases.

Tables 3-1 through 3-6 are believed to be self-explanatory in so far as the objectives of the present study are concerned and will be discussed only in the context of review of past SPOC research and possible future directions in Section 8. More exhaustive studies of the user requirements presented here might well be made in the future. However, prior to initiating such a study, there are a number of policy questions that must be answered, on a high government level, so that realistic and meaningful ground rules can be established.

Two of the more important of these are:

1. Will an operational satellite system acquire data over the whole world ocean and provide such data to other countries, or will data be restricted to the U. S. only?

2. If the former is true, how should these countries be approached for their requirements and what type of weighting should be applied?

The time for answering these questions is rapidly approaching. ERTS A&B, test systems, are presently configured only to obtain data over the United States as a result primarily of their restricted data transmission system. However, tape recorders are now under development which may be ready in time for potential use on ERTS A&B. Thus, if the decision were made to do so, it may be technically feasible to obtain data from other areas using these satellites.

Also, cooperative programs have been agreed upon between the U.S. and Mexico and Brazil and aircraft data is being acquired. However, the fact remains that no international oceanographic user requirements have been solicited and the acquisition of such could alter preliminary planning for a space system. This is true especially in the areas of data transmission, i.e., tape recorders, data compression, dump stations, etc., as well as sensor configuration and geographical coverage.

Table 3-1. Compilation of User Oceanographic Requirements That are Feasible for Remote Acquisition

Use/ Application Area	Information Required by User	Ocean Features to be Observed	Geographic Coverage Required	Input Frequency	Input Timeliness	Format	Data Points Required	Parameter Range	Resolution			Comments
									Spatial	Spectral	Temp	
FISHERIES	• Location of areas suitable or unsuitable for fish habitation • Location of fish schools • Potential sea state conditions in operating areas	Sea Surface Temperature (Thermal) Gradients)	Local	1-4 per day	Daily	Chart, Facsimile, Radio	1 per km^2	-5° to - 35°C	500 m	NA	.5° to 1.0°C	Parameter range for various fisheries falls within the bounds given but usually does not include the whole range. For Calif coast + 12° to 27° C is adequate.
			Regional (coastal)	1-4 per day	Daily	Chart, Facsimile, Radio	1 per km^2 to 1 per 10 km^2	-5° to + 35°C	500 m to 1000 m	NA	.5° to 1.0°C	Pearcy in Oregon coast studies found SST fluctuations to be rapid and complicated. Thus his stated requirements are for 100 m and up to 0 1° C resolutions.
			Regional	Weekly	Weekly	Mag Tape, Chart, Tabulation, Facsimile	1-2 per 400 km^2	-5° to + 35°C	10 km	NA	1 0°C	In general, charts with 1 0° needed at scales of 1:100,,000 to 1.1,000,000 every week (132)
		Chlorophyll	Regional (coastal)	Weekly	Weekly	Map, Chart	1 per km^2	0.1 to 1 0 mg/m^3	100-1000 m	01µ	1 0°C	Chlorophyll concentration should be contoured every 0 2 mg/m^3 with an accuracy of 0.1 mg/m^3. Absorption peak of chlorophyll is 0 67 µ Little data acquired presently Parameter to measure is color.
		Sea State • Wave Height • Wave Length • Wave Period • Wave Direction	Regional (coastal)	Daily	Daily	Facsimile, Charts (on Board, Vessel), Radio	Regional (coastal) 1 per 20 km^2 Regional ~1 per 100 km^2	• 0-30 m • 0-300 m • 1-40 sec • 0°-360°	• .5-2 m • 25 m • 1-5sec • 2°- 5°	NA	NA	Japanese tuna vessels presently have on-board facsimile recording for sea state information Information should include historical as well as present data
		Pollution (Various Pollutants Included)	Local	2-4 per day	Daily	Mag Tape, Map	Not Specified	Various - (depending on pollutant)	30 m	.01 µ	.5°C	Most requirements have yet to be adequately defined Greatest density of data is required from near in coastal areas - bays, estuaries, harbors, marinas, and around offshore oil drilling platforms on a fairly repetitive basis
			Regional (coastal)	Daily	Daily	Mag Tape, Map	Not Specified	Various - (depending on pollutant)	60 m	01 µ	1 0°C	

Table 3-1 (Conintued) Compilation of User Oceanographic Requirements
That are Feasible for Remote Acquisition

Use/ Application Area	Information Required by User	Ocean Features to be Observed	Geographic Coverage Required	Input Frequency	Input Timeliness	Data Format	Data Points Required	Parameter Range	Resolution: Spatial	Resolution: Spectral	Resolution: Temp.	Comments
(Cont'd)	(Cont'd)	Currents • Size and Location • Direction • Velocity	Regional	Daily	Daily	Map, Chart	1 per km^2 to 1 per 10 km^2	• 100m-2km • 0-360° • 0.5-10 knots	• 500 m • 5° • 1 knot	.01 μ	1°C	Current boundaries (fronts) are the areas of interest and may be delineated by color, temperature, or other anomalies
			Regional Global	Weekly	Weekly	Map, Chart	1 per 500 km^2	• up to 50 km • 0-360° • 0.5-10 knots	• 1000 m • 5° • 2 knots	01 μ	1°C	
		Salinity	Local (coastal)	Daily	Daily	Charts, Maps	Not Specified	0 01-40 parts per thousand	See Com-ments	NA	NA	Observational accuracy of 10% in coastal zone and 1% in estuaries.
		Upwelling	Regional (coastal)	Daily	Daily	Map, Chart	1 per 10 km^2	500 m to 1000 m	500 m	01 μ	1°C	Requirements are comparable to those for currents.
			Regional	Weekly	Weekly	Map, Chart	1 per 500 km^2	Not Specified	1000 m	.01 μ	1°C	
		Ocean Color	Local	Daily	Daily	Map, Chart, Graph, Photo	1 per km^2	NA	100 m	01 μ	NA	Information on water color is important for the measurement of a number of phenomena. Information on color can be obtained either in an image format (camera) or spectral format (spectrometer, spectrophotometer). Both techniques have certain advantages. See Section 4.10.
			Regional (coastal)	Daily	Daily	Map, Chart, Photo	1 per 10 km^2	NA	100 m	01 μ	NA	
			Regional	Every 5 days	Every 5 days	Map, Chart, Photo	1 per 500 km^2	NA	1000 m	.01 μ	NA	
		Fish Schools • Photography • Luminescence • Spectral Detection • Slicks	Regional (coastal)	1-4 a day in area of fishing activity	Near Realtime	Facsimile, Radio	Not Specified	10 m to 7 km	15-30 m	150 Å	NA	The range of light emitted by low and high concentrations of luminescing organisms has not been specified. Fish schools have a wide size range.

Table 3-2. Compilation of User Oceanographic Requirements That are Feasible for Remote Acquisition

Use/ Application Area	Information Required by User	Ocean Features to be Observed	Geographic Coverage Required	Input Frequency	Input Timeliness	Data Format	Data Points Required	Parameter Range	Resolution: Spatial	Resolution: Spectral	Resolution: Temp.	Comments
MARINE TRANSPORTATION	• Potential sea state conditions in operating area • Optimum routing • Location and position of shoal areas	Sea State • Wave Height • Wave Length • Wave Direction	Regional (coastal)	2-4 per day	Near Realtime	Facsimile, Radio	1 per 20 km^2	• ~30 m • 0-300 m • 1-40 sec • 0-360°	• 0 5-2m • 25 m • 1-5 sec • 2°-5°	NA	NA	Because of density of traffic more frequent and more accurate information required in certain regional areas Most requirements for height resolution were about 2 meters, small craft require sea state information associated with >10 knot winds Travelers Research Report (4) specified 10° for coastal and 20° for open ocean wave direction.
			Global	1-2 per day	Near Realtime	Facsimile, Radio	1 per 100 km^2	• ~30 m • 0-300 m • 1-40 sec • 0-360°	• 0 5-2m • 25 m • 1-5 sec • 2°-5°	NA	NA	
		Currents • Extent • Velocity • Direction	Regional (coastal)	Daily	Daily	Facsimile, Charts, Reports	1 per km^2 to 1 per 10 km^2	• 100m-25 km • 5-10 kt • 0-360°	• 500 m • 1 kt • 3°	01 μ	1°C	These requirements were derived from various reports Individual users did not specify requirements other than that they would like information on ocean currents.
			Global	Weekly	Weekly	Facsimile, Charts, Reports	1 per 500 km^2	• Up to 50 km • .5 to 10 kt • 0-360°	• 1000 m • 2 kt • 5°	.01 μ	1°C	
		Icebergs	Regional	Semi-Weekly to Daily	Within 12 hours	Facsimile, Charts, Radio, etc.		15 m and up.	15-20 m	NA	1°-2°C	Location of icebergs to accuracy of ±8 km Requirements specified are from U S Coast Guard
		Sea Ice • Extent • Thickness • Type	Regional	Daily-Weekly	Within 12 hours	Facsimile, Charts, Radio, etc		• NA • 0-20 m • NA	• 30-100 m • <1m • 30-100m	NA	• 1.0-2 0°C • NA • NA	For long-range ice forecasting, kilometer resolution is adequate Sea ice thickness required for such shipping routes as Great Lakes, Northwest Passage, etc.
		Bathymetry	Global (coastal) and shoal areas	NA	NA	Charts, Maps		~0-200m	<2m near shore 5m farther from shore Horizontal ~30 m	02 -	NA	See chart on Bathymetry. Safe surface navigation requires that all ocean areas with charted depths less than 30 m that are in doubt be verified.

Table 3-3. Compilation of User Oceanographic Requirements That are Feasible for Remote Acquisition

Use/ Application Area	Information Required by User	Ocean Features to be Observed	Geographic Coverage Required	Input Frequency	Input Timeliness	Data Format	Data Points Required	Parameter Range	Resolution			Comments
									Spatial	Spectral	Temp.	
OCEAN INDUSTRY • Oil/gas drilling • Construction • Recreation • Submersible operations • Mineral exploration and exploitation • Cable laying	• Potential sea state conditions in operating areas • Water depth in operating areas • Bottom characteristics in operating areas • Pollution in operating and recreation areas	Sea State • Wave Height • Wave Length • Wave Period • Wave Direction	Local	Every 3 to 6 hours	Realtime	Facsimile, Teletype, Computer Terminal	Not Specified	• 0-30 m • 0-300 m • 1-40 sec • 0-360°	• .3m • NA • NA • 2°-5°	NA	NA	Weather forecasts good for up to 2 weeks are required by many marine industry users. Wave height is the most requested information
			Regional	Daily	6-12 Hours	Facsimile, Teletype, Computer Terminal	Not Specified	• 0-30 m • 0-300 m • 1-40 sec • 0-360°	• .3-1m • NA • NA • 2°-5°	NA	NA	
		Pollution	Local	Daily	Daily	Radio, Charts, Photos	Not Specified	Various-depending on pollutant	10-20m	To be Determined	1°C	Recreation industry is eminantly interested in pollution although they are not sure of their requirements. Requirements specified here are those of the scientific community.
			Regional	Weekly	Weekly	Radio, Charts, Photos	Not Specified	Various-depending on pollutant	10-20m	To be Determined	1°C	
		Water Depth	Global (coastal and shoal areas)	NA	NA	Charts, Maps	Not Specified	0-200 m	Vertical-<2m near shore, <5m farther from shore Horizontal ~30m	.02 µ	NA	See chart on Bathymetry
		Bottom Characteristic	Global (coastal)	NA	NA	Charts, Maps	Not Specified	0-200 m	Horizontal ~30m	.02 µ	NA	Information required includes consolidated or unconsolidated, type, plant growth, and topography.

Table 3-4. Compilation of User Oceanographic Requirements That are Feasible for Remote Acquisition

Use/ Application Area	Information Required by User	Ocean Features to be Observed	Geographic Coverage Required	Input Frequency	Input Timeliness	Format	Data Points Required	Parameter Range	Resolution: Spatial	Resolution: Spectral	Resolution: Temp.	Comments
MAPPING AND HYDRO-GRAPHY	• Location and position of shoal areas • Water depth in coastal and shoal areas	Water Depth (Ocean Bottom)	Regional (coastal)	As required	NA	Analog, Digital, Chart, CRT Display	NA	~0-200 m	Horizontal ~30m (camera) Vertical-~2m near shore, ~5m away from shore	.01 μ	NA	Charts at scales of at least 1 50,000 are required ESSA/ C&GS has the major responsibility for the coastal areas of the U S and its possessions. The Navy has the major responsibility for providing bathymetric maps of non U S. areas The measurement of ocean color using cameras and scanners shows the highest feasibility for space deployment. Pulsed laser techniques possess very high resolution (2m) from aircraft altitudes Other techniques include wave refraction analyses and thermal anomaly detection.
			Global (coastal)	As required	NA	Analog, Digital, Chart, CRT Display	NA	~0-200 m	Horizontal ~30m (image) Vertical ~2m near shore, ~5m away from shore	.01 μ	NA	

Table 3-5. Compilation of User Oceanographic Requirements That are Feasible for Remote Acquisition

Use/ Application Area	Information Required by User	Ocean Features to be Observed	Geographic Coverage Required	Input Frequency	Input Timeliness	Data Format	Data Points Required	Parameter Range	Resolution			Comments
									Spatial	Spectral	Temp.	
WEATHER FORECASTING AGENCIES	Accurate and synoptic information on those ocean features affecting: • Ocean circulation • Heat budget • Weather	Sea Surface Temperature	Global	4 per day*	Realtime*	Digital	1 per* 50,000 km²	-3° to +35°C	500 km*	NA	1°C	A wide range of data input frequencies is called for depending on how the data is to be used. For developing global prediction models historical data is sufficient. For realtime updating of model and forecasting - near realtime data is needed
		Sea Ice • Thickness • Extent	Regional	Daily-Weekly	24 Hours	Digital	• 1 per km² • NA	• 0-20 m • NA	• 1 m • 1 km	NA	1°C	
		Sea State	Global	Daily	24 Hours	Digital	Not Specified			NA	NA	Information on general sea state conditions is required, however, not in the detail that is required for the shipping industry.
		Currents • Extent • Velocity • Direction	Global	Daily-Weekly	24 Hours	Digital	1 per 500 km²	• Up to 50 km² • .5-10 kt • 0°-360°	• 1000m • 2 kt • 5°	01 µ	1°C	

*U.S. Weather Bureau requirement

Table 3-6. Compilation of User Oceanographic Requirements That are Feasible for Remote Acquisition

Use/ Application Area	Information Required by User	Ocean Features to be Observed	Geographic Coverage Required	Input Frequency	Input Timeliness	Data Format	Data Points Required	Parameter Range				Comments
									Spatial	Spectral	Temp	
SCIENTIFIC AND CULTURAL STUDIES	Heat transfer Thermal pollution Thermal structure Forecasting currents	Sea Surface Temperature	Local	Daily or	NA	Digital, Computer Contoured Isotherm Charts	1-5 per km²	-5°C to + 35°C	25-500m	NA	0.1° to 1 0°C	Most requirements are for sporadic data over small areas. Data is used for a wide range of studies as is indicated in the spread of the requirements.
			Regional (coastal)	Daily or As required	NA	Chart, Digital	1 per 20 km²	-5°C to +35° C	<1 km	NA	.1° to 1.0°C	
			Regional	As required	NA	Chart, Digital	1-2 per 400 km²	-5°C to +35° C	1-10 km	NA	3 to 1 0° C	Requirements are for tuna research in the Eastern Tropical Pacific fishing region.
	Chlorophyll	Ocean Color	Regional (coastal)	Daily	NA	Maps, Analog, Digital	2-4 per km²	0.1 to 1.0 mg/m³	500 m to 1000 m	01µ to .0075 µ	NA	
	Upwelling El Nino	Surface Salinity	Local	As required	NA	Analog, Digital	Not Specified	01-40 parts per thousand	Not Specified	NA	Not Specified	Basic research only - it appears micro-wave techniques operating at 1 GHz may be able to determine salinity in coastal areas
	Radar scattering cross sec	Wind/Sea State	Local	As required	NA	Analog, Digital	Not Specified		Not Specified	NA	NA	
	Sea surface topography	• Currents • Tides • Eustatic changes in sea level	Regional	Daily	NA	Map	1 every 2-3 sec for narrow features 1 every 10-20 sec for wider features	10 m	Vertical ± 1 to 1.0 m	NA	NA	Theoretical research into electromagnetic wave scattering from a non-linear sea is a necessary step towards 10-cm resolution of sea surface heights.
	Water depth	Ocean Color	Local	As required	NA	Photo	NA	Maxi Water penetration	~30 m	.01 µ	NA	Films, filters, spectrum and data processing techniques need to be determined to insure maximum water.depth penetration.
	Fish schools/ species	Bioluminescence	Regional (coastal)	As required	NA		To be Determined	Not Specified	~15 m	NA	NA	An image intensifier has been tested to determine its applicability for locating fish schools.
		Fish Oil Slicks	Regional (coastal)	As required	NA	Spectral Curves	To be Determined	To be Determined	Not Specified	Not Specified	NA	
		Pelagic Fish Species	Regional (coastal)	As required for test	NA	Spectral Reflectance	Not Specified	Visible Spectrum-4-.7µ	~15 m	200 Å	NA	Laboratory tests have been successful, aircraft tests are now required to continue feasibility studies.

SECTION 4
SIGNIFICANT ACHIEVEMENTS IN REMOTE SENSING OF THE OCEAN

4.1 INTRODUCTION

This section provides a comprehensive discussion of progress to date in determining the feasibility of using airborne and spaceborne instruments for acquiring information on the marine environment. Included are studies and experimental flight tests which have been sponsored not only by SPOC but also by other agencies, i.e., NASA, ESSA, Interior Department, Navy Department, etc. The discussion of research in addition to that sponsored by SPOC, as specified in the contract, is believed necessary in order to provide a true appraisal of progress in this wide-ranging and multi-faceted endeavor. During the course of this study CSC was provided with some 75 documents for review which reported on tasks either sponsored or technically monitored by SPOC. Forty-three of those documents were found to contain new and original research material relating directly to SPOC's interests in remotely sensed oceanographic data. These are discussed here. The remaining documents, while of value in the overall development of remote sensing capability, represented indirect material which is discussed in general in this report. These documents include papers developed as a result of basic research reported in other documents, bibliographies, monthly contract status reports, and the like. Thus, while no direct reference is made in this report to most of these types of reference documents, the applicable research is discussed in conjunction with other documents. A small number of original research documents were purposely not discussed as they either presented results which were invalidated by later work or they did not, in the opinion of the reviewers, present significant research advancement. Figures 8-1 through 8-3 of Section 8 lists, analyzes, and discusses those specific studies funded by SPOC and their impact on the overall program.

When considering a spaceborne system for use in observing the marine environment, there are two modes which may be considered. The first mode would be direct observation of marine phenomena by instruments in the satellite. The second mode would relay information via the satellite. Such information would be transmitted to the satellite from an ocean-based observation platform. Information included in the latter concept covers a wide range of ocean

parameters, subsurface, surface, and above surface, and is limited only by the capability of the buoy in question. Thus it is primarily a data transmission problem with a communications satellite. This study does not relate to this situation and addresses itself only to remote sensor data acquisition systems.

An extensive area of research and development not included in this compilation is that pertaining to military applications. These developments and capabilities are, for the most part, classified, hence are not directly available to a civilian space program. However, much of the progress achieved by the military over the past few years has provided valuable fallout for civilian applications.

Because of the complex nature of the potential sensor and platform systems, the wide spectrum of applications, the numerous government agencies and industrial concerns involved, and time allocated for this phase of the study it is a difficult task to completely survey all research that is being conducted. Thus, in this section we did not include all recent research, however, we have attempted to summarize the research on those techniques that appear to have the greatest potential for contributing to an improved understanding of the marine environment.

This section is divided into 12 subsections which relate to those ocean phenomena/parameters that appear to be measurable using remote sensor techniques either from aircraft or spacecraft and were previously identified in Section 2. They are in order of occurrence in the section:

Marine Organisms
Pollution
Sea Surface Temperature
Sea State/Wind
Ocean Currents
Sea Ice
Icebergs
Heat/Energy Exchange
Ocean Color
Bathymetry
Sea Surface Topography

4.2 MARINE ORGANISMS

4.2.1 Introduction

A healthy and viable fishing industry can make a significant contribution to the United States' economy and provide needed food resources. Attaining a competitive fishing industry will require a multiple attack on a number of problem areas that exist within the industry. These problems have been discussed in reference 82. We have examined the problems which satellites can help solve. There appear to be two general types of applications of an expanded system of satellite observations to commercial fishing operations. The most significant application is in the use of satellite acquired data as a part of an integrated research effort designed to identify and quantify the parameters determining the temporal movements and concentration of fish in the oceans (26). The second major contribution is to the direct location of fish concentrations.

4.2.2 Indirect Detection of Fish Schools - Development of Prediction Models

The relatively simple prediction models now visualized for aiding in the location of edible ocean organisms relate the distribution, abundance, and availability of these organisms to certain physical characteristics of the environment and to the availability of food. The tremendous coverage, accurate positioning, and rapid communication afforded by the use of satellites, alone and in conjunction with surface and subsurface platforms, should increase enormously the rate at which required information can be accumulated and converted into improved predictive models (24). Such improved models may result in large-scale reductions in search time and therefore in increased catch per unit of time.

Inputs required for such models include information on several ocean parameters, some of which have already been remotely sensed from space, but without the accuracy and resolution required, and others which are believed feasible for acquisition to some degree and thus are under study. These parameters, listed with previous acquisition platforms, are as follows:

Sea surface temperature, mixed layer (Nimbus and ITOS)

Surface currents (Nimbus, Gemini, Apollo)

Color of water (Gemini and Apollo)

Surface winds, sea state (Aircraft)

Chlorophyll (Aircraft)

Salinity (Theoretical studies only)

These factors influence the internal supply rate of nutrient elements to the surface euphotic layer, which in turn govern the primary production, or carbon fixation, of marine plants on which all the marine fauna depend, either directly or indirectly. The aggregation of commercially useful fish species is subsequently influenced by these concentrations of marine plants.

To provide a useful forecasting service for the commercial as well as the sport fisherman, more than periodic charts of some or all of the above parameters will be required. A forecasting center will be required, within an appropriate government agency, where data on all pertinent parameters from all collecting sources can be combined with operational information, then interpreted and distributed in a form most useful to fishermen.

Each of the aforementioned parameters for fisheries applications will be discussed to present the status of techniques for acquiring such information, either from aircraft or spacecraft mounted instruments.

4.2.2.1 Sea Surface Temperature

Sea surface temperature has been the oceanographic parameter which has received the most attention in so far as actual sensing with spaceborne instrumentation is concerned. This has resulted primarily because meteorological sensors, the High Resolution Infrared Radiometer (HRIR), and the Medium Resolution Infrared Radiometer (MRIR), designed for cloud studies are also marginally applicable for determination of ocean surface temperature. The temperature of the surface layer of the ocean is of fundamental importance in the thermodynamics of the upper ocean and lower atmosphere and in their interaction. Thus sea surface temperature enters into predictive models for both ocean and atmosphere and is of great importance in many phases of oceanography.

Because of the importance of sea surface temperature to many different phases of oceanography, this parameter has been treated separately in Section 4.4. It is discussed here only in relation to the indirect detection of fishery resources. Several of the publications reviewed during this study discussed the application of aircraft and spacecraft derived sea surface temperature and its relation to the indirect location of fish (14, 24, 26, 89, 95).

Charts of the sea-surface temperature are of demonstrable importance to fisheries for estimating distribution, abundance, and availability of fish. For example, the Bureau of Commercial Fisheries (BCF), Fishery Oceanography Center at LaJolla, California, publishes periodic sea-surface temperature (SST) charts of the eastern pacific for use by the tuna fishery. At the present time, data for these charts are obtained from cooperating ships and aircraft, both government and private.

An extensive survey of the albacore environment was conducted during the summer of 1969 along the Oregon coast by W. Pearcy of Oregon State University (95) in conjunction with the Coast Guard, NASA, the Bureau of Commercial Fisheries (BCF) and numerous albacore fishing fleet operators. A prime parameter correlated to the albacore population was SST. The areas temperature pattern was found to be complex and rapidly changing. Detailed analyses were not available at the writing of this report, but preliminary indications are that SST does influence the migration and distribution of the albacore tuna. Both ship and aircraft SST surveys were carried out during the environment survey to determine, not only the temperature environment in which albacore tuna were actually netted, but also the pre- and postenvironmental temperature conditions. Sea surface temperature was measured on all flights using PRT-5 radiation thermometers. Multispectral scanner data was obtained from the University of Michigan aircraft which also took part in the survey.

In another aircraft remote sensing survey, NAVOCEANO (89) conducted a study to aid the Icelandic fishing industry. An aircraft equipped with an airborne radiation thermometer (ART), described in Section 4.4.3.1, was used to define the boundary between the tongue of polar water projecting southward to the east of Iceland and the warmer eastern Atlantic water mass. This survey was completely successful. Since arctic water masses have been changing their positions rather dramatically recently and since the herring fishery follows the

the temperature gradient quite closely, the Icelandic Fishermen have become quite concerned about losing their fishery and are critically interested in this application of remote sensing.

Although, as indicated in Section 4.4, satellite borne infrared radiometers have been used to obtain sea surface temperature data, the present review did not uncover instances in which such data have been used for indirect location of fish concentrations. Reasons for this are inadequate temperature as well as spatial resolution. User requirements are $1^{\circ}C$ and ~ 2 km (spatial) with HRIR data providing $3-4^{\circ}C$ and $\sim 10-12$ km (spatial resolutions.)

4.2.2.2 Chlorophyll

The abundance of chlorophyll is another important indirect indicator of fish concentrations, especially if information on chlorophyll content is used in conjunction with sea surface temperature information. Because it is associated with plant life, chlorphyll concentration is an index to the amount of phyto-plankton present. Regions with high phytoplankton abundance can support large populations of herbivores and these in turn support successive links in the animal food chain, many of which are of economic importance. To be of maximum usefulness chlorophyll must be detectable in concentrations as low as $0.2 mg/m^3$. This low concentration threshold appears to be significant for some fisheries, such as tuna, which are not found in lesser chlorophyll concentrations. (77)

In the ocean, chlorophyll is distributed in a nonuniform manner throughout the euphotic zone, which may range from 10 to 100 m in depth. A rough estimate is that most backscattered light arises from the first 10 m. Thus, chlorophyll concentrations can reasonably be expected to be measured in that interval only by remote sensing techniques. In terms of photosynthetic production this does not present an acute problem since the light energy that drives photosynthesis decreases logarithmically with depth and the phyto-plankton near the surface are responsible for the majority of the production. Therefore, in a majority of cases high phytoplankton concentrations in surface waters will in general be indicative of a productive water mass (77).

Chlorophyll affects the visible spectrum in two characteristic ways which are described below. These effects make it feasible to consider establishment of chlorophyll concentrations in the ocean by remote sensing.

One effect of chlorophyll on the visible spectrum is to cause large changes in the ratio of green (.54 μ) to blue (.46 μ) in the spectra of backscattered light. It has been shown (18) that such changes can be remotely detected from low altitude aircraft flights over water areas where relatively large changes in the chlorophyll concentration occur in the upper 10 meters of the ocean.

A second effect of chlorophyll on the visible spectrum is to produce specific absorption at 6700Å which can be measured spectroscopically. The specific absorption of chlorophyll a is illustrated in Figure 4.2-1. The absorption coefficients of water plus chlorophyll (for a chlorophyll concentration of 1 mg/m^3) in the vicinity of 6700Å are given in Table 4.2-1 along with the percentage transmission through a meter of water at this wavelength.

Table 4.2-1 Absorption Coefficients and Transmission in Chlorophyll and Pure Water (77)

Wavelength Å	Chlorophyll in Water (1 mg/m^3)		Water (100 cm)	
	E	%	E	%
6500	0.0035	100	0.1300	74
6700	0.018	95	0.1590	70
7000	0.0018	100	0.2150	61

Water absorption is monotonic in this spectral interval, while chlorophyll absorption is not. The differential brightness of backscattered radiation in the absorption band and in an adjacent reference band is associated with the amount of chlorophyll present.

Recently data on chlorophyll have been obtained from aircraft using a water color spectrometer (WCS) and a widerange image spectrophotometer (WISP) both developed by TRW (8, 18, 104). The primary difference between these instruments is that the WCS measures the spectra (.4 - .7μ) of the upcoming radiation from the water in only one spatial: element with a spectral resolution of 5 to 7.5 nanometers, while the WISP is designed to measure simultaneously the color of twenty spatial elements over a spectral region of .35 to .75μ.

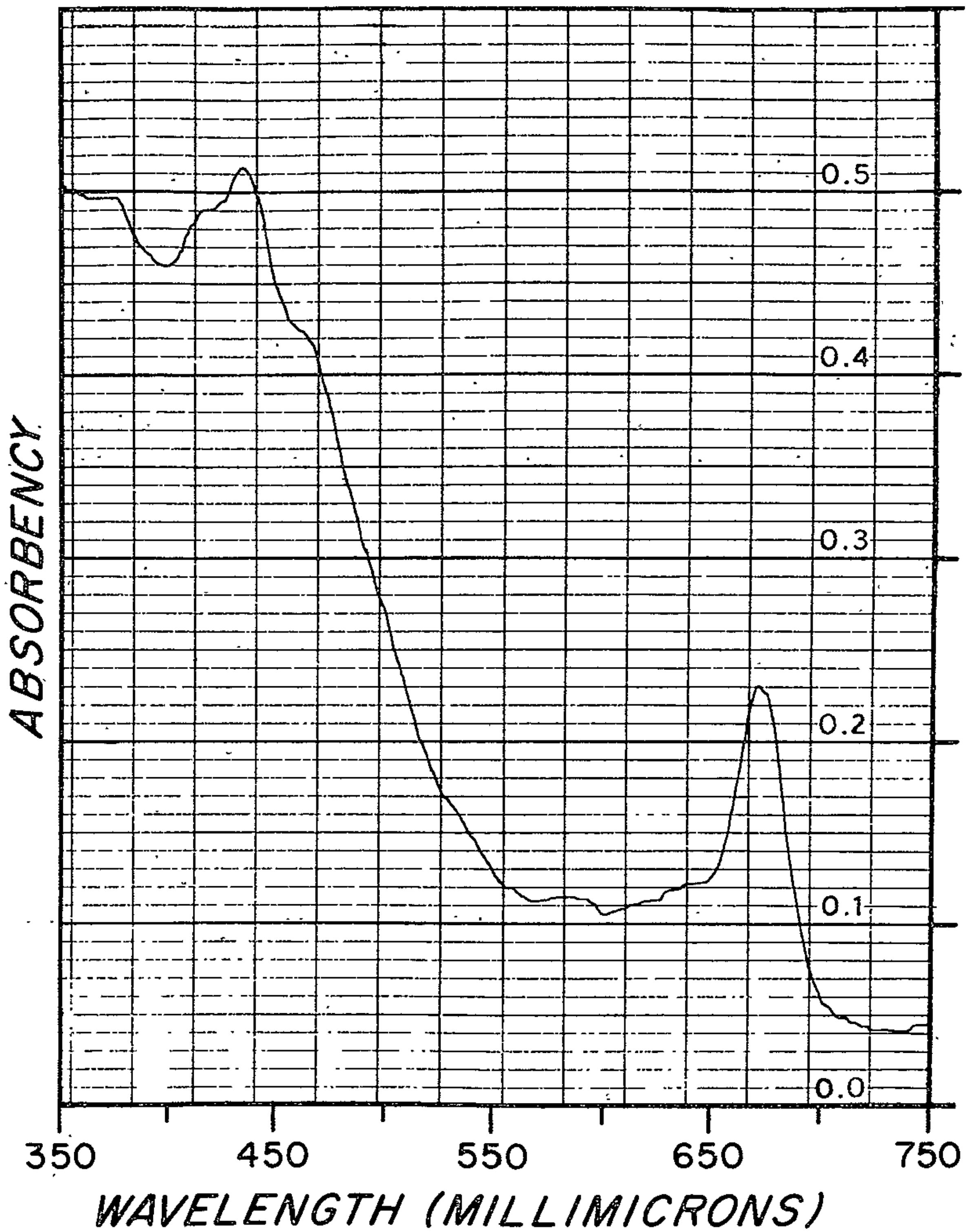


FIGURE 4.2-1 Absorbency of chlorophyll a. (77)

Additional information on these instruments can be found in reference 8.

Experiments using the above instruments on aircraft, singularly or in combination, have been conducted over a variety of water masses exhibiting widely different known chlorophyll concentrations (8, 18). Results of these studies showed that large differences in color occur from areas in the ocean having different chlorophyll concentrations and that they can be recorded from aircraft. Because of the consistency of the results and in view of the shift in the band of maximum transparancy from blue to green which occurs when minute amounts of chlorophyll and associated carotenoids are present in sea water, it is probable that these substances were the primary cause of the observed color differences.

It is noteworthy that the spectral effects of increased chlorophyll concentration are nonlinear. With added amounts of chlorophyll, the amount of water remaining constant, the band of minimum absorption, and hence the color, approaches asymptotically to the wavelength of minimum absorption for chlorophyll at .56 μ. Consequently most of the color shift occurs as a result of the addition of the first 2 or 3 mg/m^3 of chlorophyll to clear sea water (159).

Such anomalous results as were found are believed, by the investigators (18), to be due to differences in times within paired observations, to differences in surface reflection, to scattering of light by the atmosphere, and to the presence in the water of material,other than chlorophyll, affecting the light selectivity. If such interference can be eliminated, or identified and allowed for, consistent chlorophyll detection in the surface water layers by remote sensing from aircraft is possible.

No information was found in the literature concerning actual sensing of chlorophyll from spacecraft, nor were any studies found which assessed the requirements on spacecraft instrumentation for successful chlorophyll sensing or the probability of success. It was learned, however, from personal interviews at TRW that a spectrophotometer is being built for high altitude test in the NASA/MSC aircraft program.

4.2.2.3 Salinity

One of the most important parameters of the hydrosphere is its salinity. The salinity of the surface layer of the sea is usually 34 to 37 o/oo. Near coast-

lines, the salinity may vary between 5 o/oo and 37 o/oo due to the influence of coastal runoff of precipitation or river outflow. Studies of the application of remote sensor technology, i. e. microwave radiometry, to the determination of salinity have been limited. In one laboratory study of note, J. Paris (92) found that, for a number of microwave frequencies between 1 GHz and 34 GHz, salinity affects the polarized brightness temperature significantly at a frequency of 1 GHz and insignificantly at the other frequencies. A number of assumptions were made relative to environmental conditions in order to arrive at these conclusions. These assumptions can be found in reference 59.

At this early stage of investigation it would be premature to make any predictions as to the possibility that the use of passive microwave radiometry could in fact determine salinity concentration from spacecraft altitudes. However, the feasibility has been shown by these preliminary studies, and the technique might be able to survey salinity along coastal and river regions. More extensive experiments both on the surface and from aircraft are needed.

4.2.2.4 Water Color

The color of the water is one of the fundamental measurement parameters of the ocean and can be measured by remote sensing techniques. Of greatest importance are the very slight and constantly changing color differences that occur within large bodies of water and may relate to anomalous conditions.

Water color has been used in the past and is presently under increased study for the measurement of the oceans biological activity through chlorophyll detection (see Section 4.2.2.2). In addition, it now appears possible to distinguish different water masses and to detect water pollution, both of which have a direct bearing on the oceans biological activity. A more detailed discussion on ocean color can be found in Section 4.10.

4.2.2.5 Surface Currents

Information regarding ocean currents can be utilized in a number of ways. For the fishing industry, where changes in temperature and nutrient levels affect the habitats of fish, the charting of currents from space on a global and quasi-synoptic basis will be valuable.

One of the principal parameters defining the boundary of an ocean surface current is the difference in temperature between the surrounding ocean water and the current. Temperature differences between these two water masses may vary between 2^{o} and $10^{o}C$. This significant temperature difference can at present be detected, from aircraft or spacecraft, using remote sensors operating in the infrared spectrum. More detailed information on the remote sensing of ocean currents can be found in Section 4.6.

4.2.3 Direct Detection of Fish Schools

The second major impact of an operational satellite system on commercial fishing operations would be on the direct location of pelagic fish concentrations. It is unlikely that satellite observations could contribute directly to the efficiency of demersal fisheries. However, satellite observations may possibly be developed to the point where the presence of schooling pelagic fish such as the high-valued tuna and tuna-like fish that occur over wide areas of the Pacific, Atlantic, and Indian Oceans, could be sensed directly from space.

A number of studies have and are being conducted to determine the applicability of various techniques to this problem. Presently a number of techniques are used on an operational scale from low flying aircraft for the location of fish stocks. These include both direct observation and photo-reconnaissance. A number of other techniques are currently under investigation for the purpose of determining their feasibility for providing useful data to various fishery organizations and include the detection of the following parameters:

- Bioluminescence,
- Fish oil slicks, and
- Fish schools - visible sighting (spectral detection, multispectral photography).

4.2.3.1 Bioluminescence

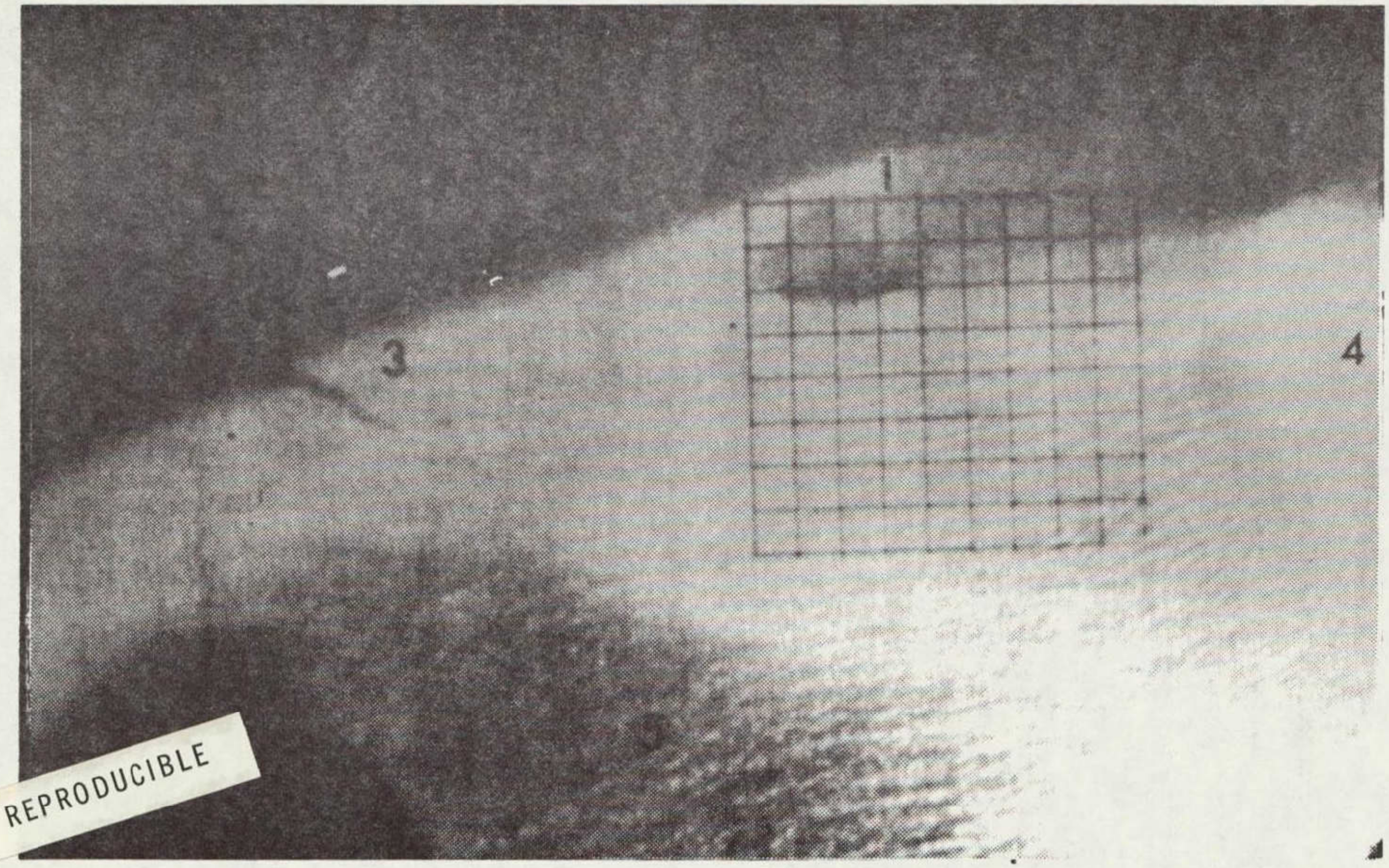
One approach to the problem of locating and identifying pelagic fish stocks, which shows significant potential, is the use of low-level light sensors, such as

image intensifiers, to detect the bioluminescence associated with most fish schools. The Spanish mackerel fishery which yields an annual catch of 3 to 4 million kilograms serves to illustrate the potential application of this method. In Florida this fishery is carried on chiefly with gill nets and haul seines at night. The fish are sighted by the "fire" in the water. This "fire" results from the movement of fish schools which cause luminescent organisms in the water to glow momentarily. Large schools of mackerel weighing from 5 to 10 tons are identified by individual flashes within a larger glowing sphere of bioluminescence.

During 1968 and 1969 a series of tests were conducted by the Bureau of Commercial Fisheries (BCF) (14), at Pascagoula, Mississippi, using an image intensifier (starlight scope) from an aircraft, a stationary oceanographic platform (Stage II), and surface vessels. The intesifier used in the initial studies amplifies the ambient light, in this case bioluminescence, 40,000 times. Observations were made from low altitudes of fish schools, individual fish, scuba divers, and objects towed at subsurface depths in water masses containing both low and high concentrations of luminescing organisms. These tests used the Plumbicon closed-circuit television system coupled to a starlight scope. Results of these tests strongly suggest that low-level light sensors may be used effectively from high altitudes as a means for locating and possibly identifying pelagic fish stocks over large oceanic areas.

4.2.3.2 Multispectral Photography

Oblique aerial photographs of selected areas in the Gulf of Mexico, obtained by BCF Pascagoula (14) show considerable activity of surfaced-fish schools (Figure 4.2-2). A close scrutiny of these photographs reveals that although they show the areas the schools cover and various configurations the schooling fish assume, they do not permit the evaluation of the schools as to tonnage or species. To collect sufficient "surface truth" information with which to interpret the fish school photography, BCF Pascagoula has established a Fishery Resources Assessment Program based on aerial photography, Sonar-equipped research vessels, and commercial fishing boats. The program outlines a coordinated effort to locate by aircraft and photograph the horizontal



The Photograph Shows Fish Schools at No. 1,2, and 3. Area 4 is Shallow Water with Sandy Bottom. Area 5 is Deeper Water with Mud Bottom. Item 6 is a Boat. The Grid is Used to Aid in Statistical Evaluation of Shape Changes and Aerial Extent. Each Square is About 12 by 12m. Photo was Taken from Altitude of 600 m in Gulf of Mexico.

Figure 4.2-2 DETECTION OF SCHOOLING FISH BY AIRBORNE PHOTOGRAPHY

extent of a fish school, and subsequently to catch the entire school. This process is to be repeated for numerous schools of the same species and for a selected number of species.

The extraction of the maximum information from each photograph is of primary importance. Multispectral analysis, termed "false color separation," has been developed by D. S. Ross (113, 114). This separation is accomplished by photographing a color transparency with 25 millimicron bandpass interference filters to produce a series of five negatives. The technique increases the contrast of small color differences between the successive spectral brands. Color separations have revealed information not detectable on the original record, such as schools at greater depths and the separation of fish from the background scene.

The usefulness of color separation has not been fully investigated, but the technique is expected to aid in the interpretation of photographic records. Further study will enable the evaluation as a possible standard method of analysis of photographic data. See Section 4.11 for a more detailed review of image enhancement techniques.

Another method of photographic interpretation, densitometry, has the capability of measuring and recording minute differences in the density of the film emulsion and thereby depicting details which could not otherwise be observed. The density differences depend on the film exposures. This method may allow the photographic interpreter to determine the horizontal compaction of fish within a school (14).

The BCF station at Pascagoula has been conducting studies to define the optimum spectral region for obtaining maximum water penetration and enhancing the very subtle color differences associated with some fish schools (14). Results of the study were not available at the time of this report. However, in a study conducted by D. Ross (114) he found that for recording ocean water color to obtain maximum penetration, two spectral bands are optimum, .46 - .51μ and .51 - .56μ. W. Vary (141) in a similar study found the .56μ band to be optimum. A more detailed description of the results of these studies can be found in Section 4.11, Bathymetry.

4.2.3.3. Spectral Reflectance

Many pelagic species may be identified on the basis of color or pattern, such as the distinctive color of menhaden schools. These characteristics are commonly used by commercial aircraft spotters in fishing operations to locate catchable stocks. The use of color or spectral differences by the commercial fish spotter to identify fish species, suggests that spectral analysis of the reflected radiation may reveal characteristic spectral signatures. This technique may be used to locate and identify fish schools in their natural environment under certain conditions. During 1968, the BCF Pascagoula and TRW Systems (138) obtained spectral reflectance measurements of 15 schooling species in the Northern Gulf of Mexico. Measurements were made of single fish, fish in small groups, and fish in schools inside impoundments, using a recently developed TRW spectrometer (8, 104). The spectral reflectance curves, i. e., measurements of the intensity of reflected light versus wavelength, were obtained under natural lighting conditions from both surface vessels and a stationary oceanographic platform. Results indicate that, in general, the reflectances are separable on a species basis and are different from seawater reflectance. A gross analysis of the data, which took into consideration water and atmospheric effects for selected samples of data presented, also substantiates this difference.

Thus, the potential for using the visible spectrum for remote identification of epi-pelagic fish has been established by a rudimentary data analysis technique (138). The salient aspect of this exploratory program was the signature data obtained for naturally schooling bait fish which was taken over several days. The data was repeatable and possessed unique spectral characteristics, which could be used for unique identification.

The next step in the evaluation of remote identification is gathering data on schooling fish in a natural or near-natural environment. Data should be gathered for the same species under varying environmental conditions to establish unique spectral signatures. Requirements for a spectrometer for obtaining pertinent data, as specified by TRW (138) are:

Spectral range - .4 to .7 μ

Ground resolution - the minimum acceptable will be approximately 12 m on a side

Spectral resolution - 150 Å to 200 Å

Signal to Noise ratio (S/N) - approximately 100 desirable, 60 is barely acceptable

Field of View (FOV) approximately 2^{o}-3^{o}

The above specifications are for a design altitude of about 300 m for a scene area of 12 x 12 m and an aircraft velocity of 60 m/sec. The minimum detectable school size would be about 25 m in diameter.

4.2.3.4 Fish Oil Slicks

Preliminary studies have been conducted by Barringer Research Ltd. (10) to determine the applicability of specific spectrometric techniques to the detection of fish and mineral oils on the surface of the ocean. The results of their laboratory work show that the fish oils can be readily classified by a multiband photometric system based on the absorption spectra when the oil sample is viewed in transmission. The differentiation between fish oils and mineral oils can be done quite easily in the visible wavelength region. Thus, mineral oil slicks are readily detected and identified by their increased reflectivity whereas the fish oil slicks which do not have a large increase in reflectivity over that of sea water, are not as detectable. The ultraviolet reflection properties of the fish oils do not lend themselves to remote sensing systems. The lack of selective reflection in the ultraviolet and the surface spreading properties of the fish oils make detection and identification very difficult. The most promising area for remote sensing appears to be the thermal IR, due to the expected temperature differences in the region of fish oil slicks. Further work should investigate the energy exchange mechanisms at the fish oil ocean interface and make experimental measurements with IR thermal sensors over the ocean.

Barringer (10) thinks that there is a good possibility for developing an infrared scanner incorporating spatial filtering which will be able to discriminate fish oil slicks on the ocean surface from orbital altitudes. Recent studies using IR techniques for mineral oil detection can be found in Section 4.3.

4.2.4 Conclusions

There exist two potential applications of remote sensing to the location of edible marine organisms; these are (1) detection of environmental parameters which can be used as inputs into a predictive model which could predict those areas suitable or unsuitable for fish habitation and (2) direct detection of fish.

In the case of indirect detection of fish schools the parameters of potential value which might be measured by sensing from space are sea surface temperature, presence of chlorophyll, salinity concentration, and water color. In the case of direct detection of fish schools the parameters of potential value which might be obtained by space sensing are bioluminescent light, water color (using multispectral analysis), relative darkness as sensed by black and white photography (densitometry), spectral reflectance of fish schools, and water temperature (as it is associated with fish oil slicks).

Sea surface temperature has been measured from space using sensors primarily designed for meterological applications. State of the art is advanced to such a stage than an IR radiometer could be built to provide $1^{\circ}C$ resolution from space. The remote detection of color as it relates to chlorophyll requires additional research prior to space flight. A spectrophotometer is under construction for test in high altitude aircraft. The use of remote sensing techniques for salinity determination require extensive study prior to determining the feasibility of the microwave radiometric concept.

The various techniques for direct detection of fish schools, as mentioned above, all require extensive studies prior to designing instruments for space. They may prove to be feasible only for low altitude aircraft flights near to on-going fishing operations.

4.3 POLLUTION

4.3.1 Introduction

Pollution, its detection, abatement, and control, is a major problem of the oceans which is receiving more attention every day. Congress and the public are showing increasing impatience with large scale ocean polluters such as oil drilling companies. However, attempts at control have been minimal and pollution of our oceanic environment steadily increases.

The large scale disposition of wastes in the ocean is a growing international problem. Each body of water can assimilate certain amounts and kinds of waste products, but each body of water, including the ocean, has a limit. The pollution load in many coastal waters already has exceeded the limit. An estimated 1.2 million acres (8 percent) of the nation's shellfishing grounds have been declared unsafe for the taking of shellfish for human use due to contamination by sewerage and/or industrial wastes. A number of coastal areas have become unfit for recreational purposes. Industrial pollution alone is increasing at a rate of 4.5 percent per year despite abatement efforts (82).

Exactly what happens to this pollution after it leaves the coastal waters, i.e., how it is dissipated and what effect it has on the total oceans' biologic balance, is largely unknown at this time. Pollutants entering the oceanic system travel long distances over the Earth's surface. For example, pesticides representing a potential hazard to health have been found in the Bay of Bengal and the Caribbean Sea after traveling in the monsoon and the northeast trade winds from the African Continent.

Another problem is that of detection and tracking of such pollution as oil spills and wastes from tankers and offshore oil drilling platforms. The extent of this problem can be appreciated when one studies reports of various ships making Atlantic Ocean crossings. Thor Heyerdahl in his recent crossing of the Atlantic in RA II, reported globules of tar-like oil widely distributed across the ocean. Most likely, this is the result of the practice of tankers crews who steam clean tanks at sea prior to loading light oils or other cargo.

One critical problem in open ocean pollution control is the establishment throughout the ocean of existing levels of concentration of natural elements such as lead and mercury, which in excessive concentrations represent a serious pollution problem. This information, now lacking, is needed to establish bench-marks so that increases in concentration due to the activities of man can be identified before they become serious and so that corrective action may be taken. These requirements for ocean wide coverage represent a national application of the spacecraft capability for providing worldwide coverage.

It is readily apparent that the problem of pollution must be viewed and combated in the context of a total waste management system. The part that remote sensing techniques may play in a detection system is still to be determined. To date, only preliminary studies have been made. Information acquired from aircraft, as well as Gemini and Apollo spacecraft (130), reveals the presence of sediment, chemicals, oil, and other industrial effluvia, as well as thermal pollution, in such bodies of water as the Gulf of Mexico and the Chesapeake and Delaware Bays. IR imaging has shown promise for the detection of oil slicks on the oceans' surface. This and other recent remote sensing research, as it applies to marine pollution, is discussed below.

4.3.2 Oil Pollution Detection Using Multispectral Techniques

Remote sensors operating in the UV, visible, and IR regions of the electromagnetic spectrum have been receiving increased attention for the detection of oil slicks subsequent to the recent Santa Barbara and Gulf of Mexico spills. The technique that shows the most promise for detecting this type of pollutant appears to be thermal IR imaging.

In a recent study (31) an airborne infrared thermal mapper was utilized to determine its applicability for oil slick detection. The IR sensor system used was a North American Rockwell modified Bendix 8-14μ thermal mapper. Images of the oil spill at Santa Barbara, California showed a mottled and streaked pattern, both lighter and darker than the background sea surface. There are conflicting explanations for these apparent thermal anomalies. Because it is darker than the ambient sea water, oil should have a higher emissivity and thus should show a lighter tone on a thermal IR image. However,

reflectivity of oil films and their interface with heat exchange at the sea/air interface substantiates expectations that oil patches should register as darker (cooler) tones on a thermal infrared image. Both of these types of tonal signatures were exhibited on the IR images. It has been assumed by the investigators (31) that the lighter areas, of higher infrared emissivity, are areas where the oil has pooled into thick streamers. Patterns where the oil-polluted surface is seen as darker than the background involve areas of active upwelling at the actual blowout sites, where cooler fluid is displacing the warmer surface waters.

Densitometric color enhancement was used to aid in further discrimination of the tonal differences that distinguish oil slicks from the background water. This enhancement permits identification of any oil patches, slicks, and films that show even minor differences in density from the background water. Since the emissivity of a water body is essentially unity in the thermal IR region, oil films that exhibit a density difference against this uniform background tone can be automatically enhanced and positively identified through this processing.

From measures of areal extent, a number of extrapolations can be made regarding thickness of oil pollutants, volume of pollutants involved, and the flow rates. Precise volume estimates require highly accurate measurements that are difficult to obtain by remote sensing techniques and thus are perhaps most economically measured on the surface. But, even here, knowledge of the areal extent to which these variables are to be applied is a prerequisite that could be supplied by the remote sensing system.

Another remote sensing study of the Santa Barbara oil slick was conducted by the University of Michigan (60), using its airborne multispectral system. The purposes of this study were: (1) to locate the offshore kelp beds and determine the extent of oil impregnation; (2) to locate the oil slick and attempt to determine its thickness; and (3) to locate the areas treated with oil dispersant.

Two scanners installed in the University of Michigan C-47 aircraft operated in seventeen different wavelength bands between 0.32μ and 13.0μ. One scanner was equipped with lamps, to calibrate radiometrically the channels operating in the region below 2.5μ. The other scanner was equipped with extended blackbody sources for calibrating the thermal region.

The data acquired using this instrument were only partially analyzed at the writing of this report. In the analyzed data the slick was best contrasted against the water background in the ultraviolet, 0.32 to 0.38μ, and the infrared 8.0 to 13.5μ bands. Inspection of the imagery from the 12 channel scanner showed the slick to be brighter than the water at wavelengths from 0.32 to 0.54μ although the contrast was not as dramatic as in the UV. At wavelengths from 0.54 to 1.0μ the contrast was too weak to positively delineate the slick.

These results are in conflict with the high reflectance of oil reported by J. Bailey of TRW (8). He found that when using a spectrophotometer (WISP) operating in the visible region the same oil slick is responsible for an appreciable increase in reflectivity, particularly in the red end of the spectrum (see Figure 4.3-1). It is interesting to note that the spectral reflectivity of a thick oil film is greater in the blue end of the spectrum than a thin oil film. Conversely, a thin oil film is more reflective in the red portion of the spectrum than is a thick film.

Bailey demonstrated the effect of the oil slick by calculating the ratio of its reflectivity to that of the unpolluted water. The resulting ratio is the spectral contrast of the oil covered water to its background and is illustrated in Figure 4.3-2. This figure indicates that any visible region sensor designed to detect oil slicks on water should concentrate on the red region of the spectrum to obtain maximum contrast.

One possible cause for the difference in results of these two investigators may arise from the variation in slick conditions, primarily thickness, since the TRW measurements were made when the rupture first occurred and the flow was estimated to be 10 times larger, and thus probably thicker, than at the time of the University of Michigan experiment. Another possible cause for the difference may be the amount of dispersant being dispensed.

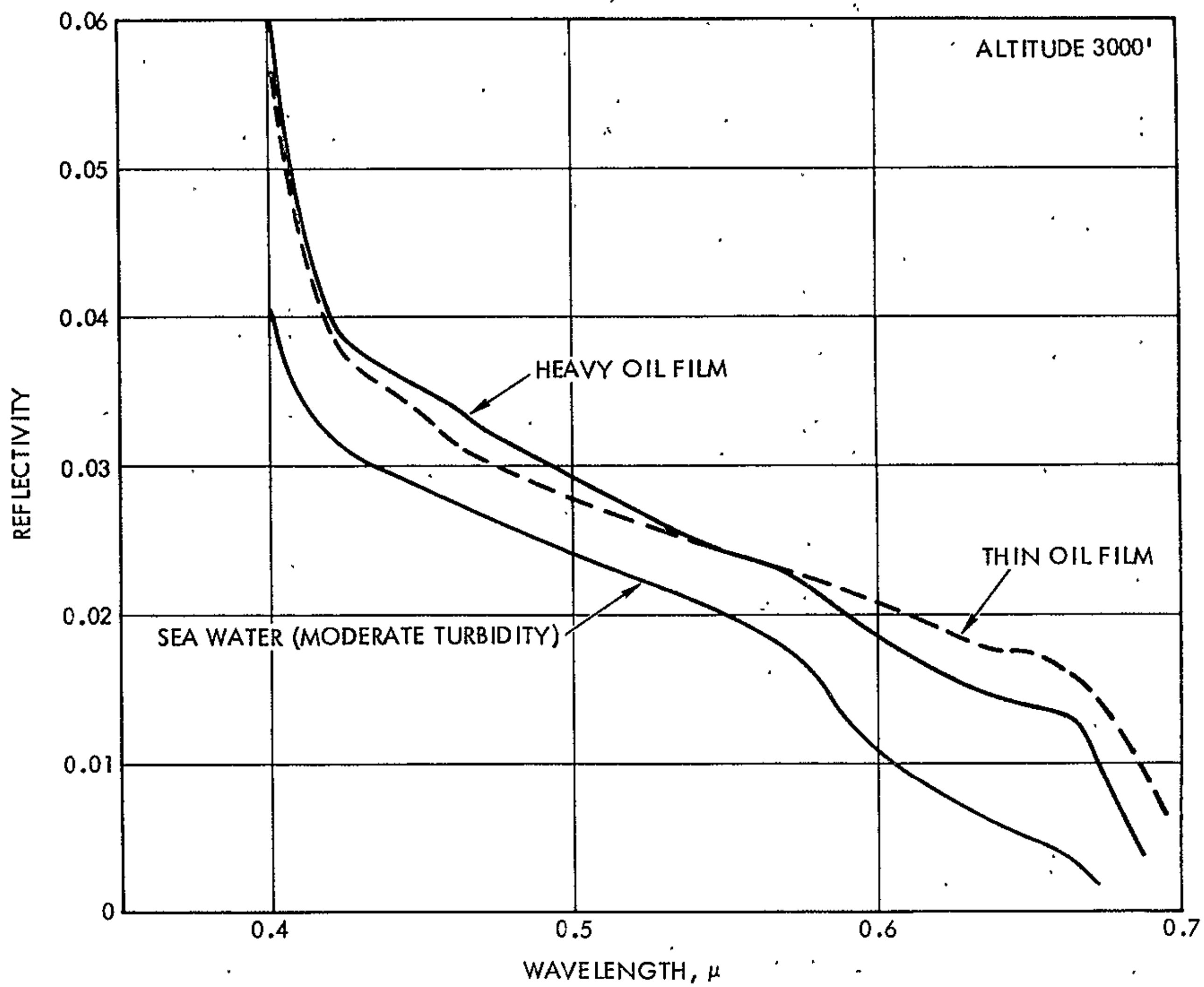


Figure 4.3-1 Spectral Reflectivity of Sea Water With or Without an Oil Layer (8)

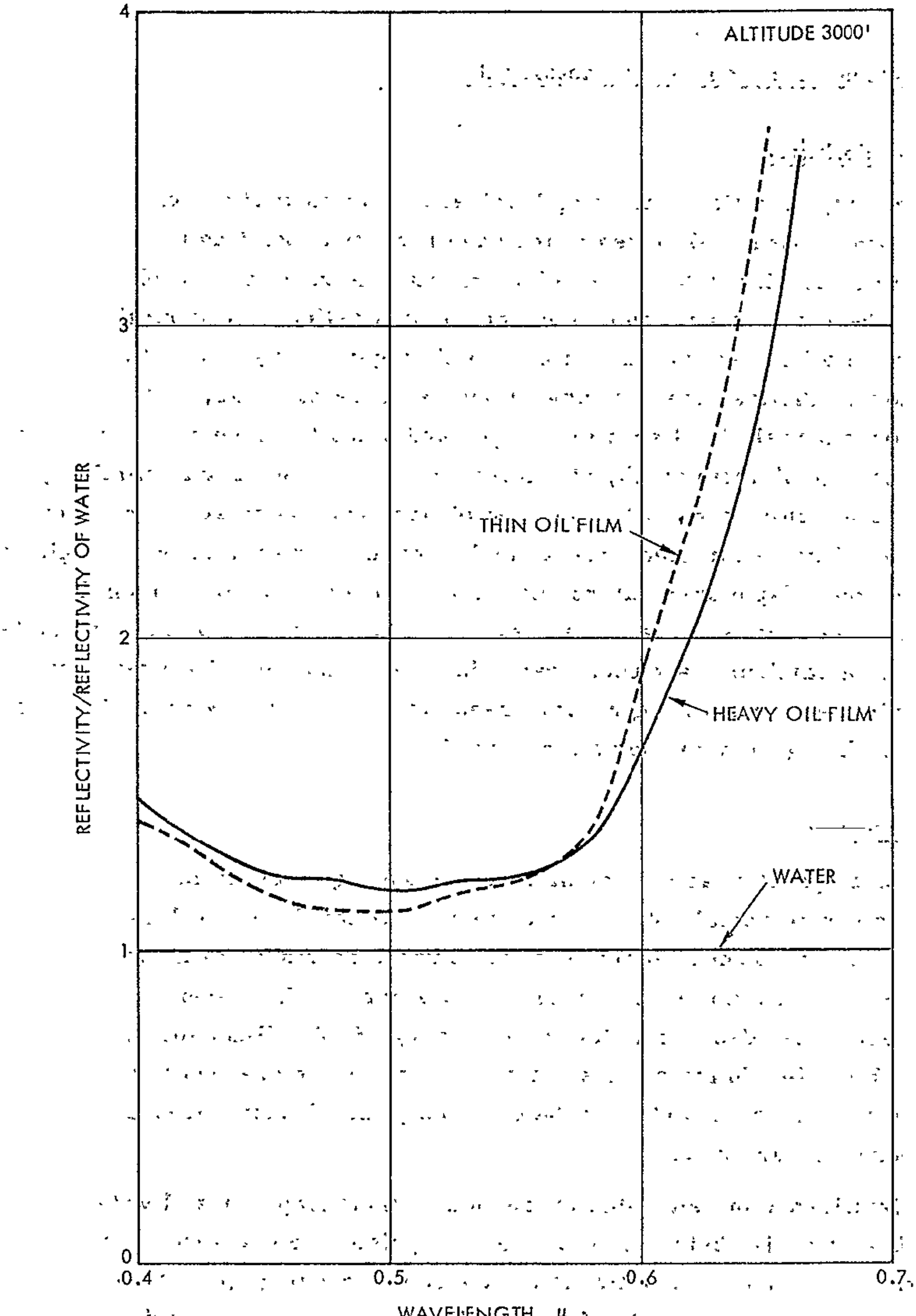


Figure 4.3-2 Reflectivity Ratio of Oil Covered Sea Water to Normal Sea Water (8)

4.3.3 Pollution Detection Using Photography

4.3.3.1 Oil Pollution

Preliminary investigations using black and white as well as color photography for detecting floating oil on sea water have been disappointing (31). The contrast between an oil patch and the adjacent water is very low. High contrast occurs only where a favorable sun angle accentuates reflectance from the oil. Even then, such oil reflectance is difficult to distinguish from sun glitter on oil-free waters. Oil-free areas of upwellings, surface currents, and localized air flows show a streaked, alternately choppy and smooth sea surface, which is difficult to distinguish from patchy oil slicks. Color photography is similarly ineffective. The color contrast between the oil film and the adjacent water is again very low. Except for areas where thick rope-like streamers of oil register as dark gray, the oil-polluted waters show a grayish-green color, which the eye readily accepts as a normal sea surface tone. It is, therefore, often impossible to tell whether a particular air photograph shows a completely oil-covered or completely oil-free surface. More work needs to be done in experimenting with multispectral photography including the near IR.

4.3.3.2 Turbidity

Color photography has the potential for indicating turbidity in shallow waters. This can be useful both in detecting natural conditions such as dispersal patterns of river sediment load and in determining man-made conditions (142). Figure 4.3-3 is an analysis of a Gemini 12 photograph by R. Stevenson (BCF) and shows sediment-laden water flowing out through Sabine Pass and the jetties of Galveston Bay. (74) In the original color photograph the dredged Houston Ship Channel, the dredged sediment, and the extremely turbid water flowing from the dredging operations are visible.

The significance of being able to frequently photograph coastal waters of Texas and Louisiana is obvious as that area comprises the greatest shrimp fishery in the world today. The turbidity caused by dredging operations, some of it illegal in the case of dredging fossil shell, was shown to be detrimental to the oyster industry. It is reported (74) that certain of these activities, detected

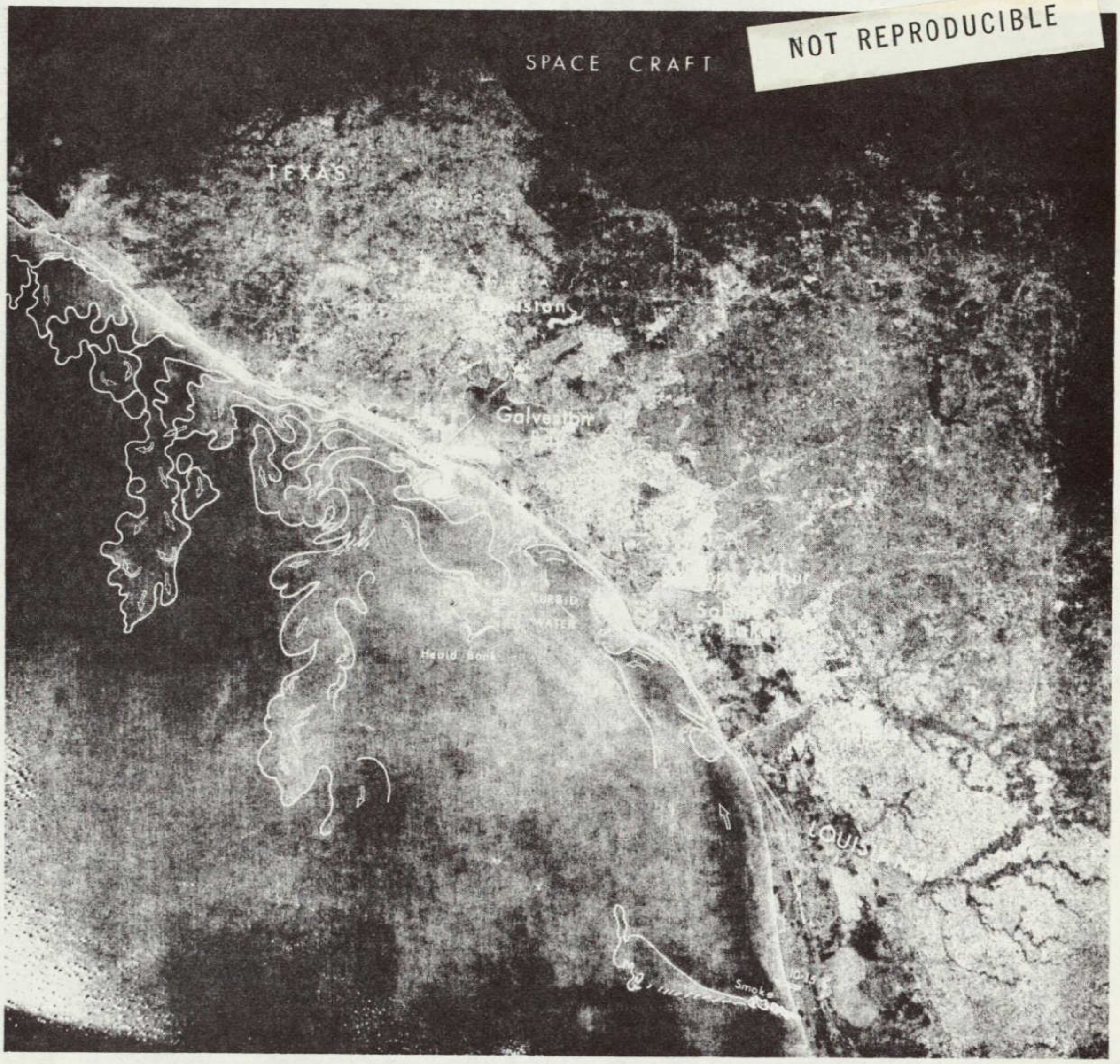


Figure 4.3-3 Analysis of Gemini 12 Photograph of Texas and Louisiana Coast - by R. Stevenson (BCF). (74)

by Gemini photography, resulted in a citation and an improvement in the water quality of the Bay.

4.3.3.3 Man-Made Effects on the Ocean Bottom

In an experiment using photography to study shallow water subsurface ecology, Kelly (51) used photographs to detect certain effects of man's activities in Biscayne Bay. These effects were: channels dredged through shoal areas, the influence of drainage canals on the bottom cover, and the results of heated water outflow from a thermoelectric power plant.

The photographs used in this study were obtained using an RC-8 camera, mounted in the NASA aircraft, and loaded with aero Ektachrome, IR Ektachrome and black and white film. The photography was obtained from approximately 3,600 meters and the water depth in the area averages about 4 meters.

Delineation of the damaged areas and the extent of damage as shown in the aerial photography proved of great value to workers in the area and to local and county governments, even to the extent that evidence was subpoenaed by the Dade County Board of Commissioners (51). The thermal effect of power plant effluents on bottom cover will be of considerable importance as the number of nuclear power plants increase. Aerial photography combined with the use of thermal infrared scanners should prove of value in monitoring changes that occur due to thermal effects of nuclear power plants.

4.3.4 Pollution Detection Using Fraunhofer-Line Spectral Techniques

Another parameter that may provide significant information on water quality is luminescence which is produced by many pollutants. The Interior Department (131) has already used Fraunhofer-Line spectral techniques to detect bioluminescence in the sea, even in daylight, and while the luminescence signature of biota would obviously have to be differentiated from that of pollutants, this kind of optical discrimination is feasible.

4.3.5 Oil Pollution Detection Using Passive Microwave Techniques

A preliminary study undertaken to determine the application of passive microwave techniques for the detection of oil pollution produced optimistic results (6). There were two objectives considered in this study. The first was the measuring of the local change in sea state due to the presence of the oil pollution. This phenomena presents very strong signals to microwave radiometers when winds in excess of 6 knots are present. It is felt by the investigators (6) that this may be a primary detection mechanism for thin oil films. The second objective considered was the direct change in the emissivity of the water surface due to the presence of oil.

In the preliminary study several measurements of sea state were obtained from a pier where thin oil films were present. These measurements show that for relatively calm seas with wind ripple (sea state 0), the radiometric temperature decreased by approximately 4° whenever the oil suppressed the ripples. For sea states of 1 or 2, thin films of oil had similar effects provided wind ripple was present. In higher sea state, the temperature decrease should be even more pronounced. Thick oil films which suppress the sea state may have different effects, however. Decreasing sea state will still tend to produce colder radiometric readings, but the increased absorption from interference effects for thicker oil films may mask the sea state effect with a resultant increase in radiometric temperature. In regards to the direct change in the emissivity of the water surface in the microwave region, a series of measurements were conducted in a small tank to verify theoretical conclusions.

Examination of the data obtained during this study reveals that oil on a water surface behaves in a manner that causes two separate and distinct effects. Thin layers of oil produce a lower radiometric temperature than the surrounding sea by reducing the number and size of small capillary waves produced by the wind. This effect can produce a signature of up to 10 degrees.

When the oil film becomes thicker, it causes the apparent temperature to increase due to the effects of a dielectric on the water surface. For an operating frequency of 38 GHz, the crossover point for these two phenomena occurs in the range of 0.1 to 0.3 mm, depending on the wind speed. Thicker oil concentrations caused a very hot signature, up to 100° at 1.0 mm thickness, to be generated.

Under a U.S. Coast Guard study, microwave radiometry is being evaluated as a technique for detection of intentional oil spills at sea. The goal is to begin prototype hardware development of an airborne system within FY 1971. As part of the investigation Aerojet-General Corporation (30), using controlled dumping of various types of oil off the California Coast, has conducted experiments which demonstrate that an oil film only 0.04 mm thick can be detected using a 0.81 cm wavelength microwave radiometer. In this test the lower dielectric constants for petroleum products relative to sea water were reflected in warmer radiometric brightness temperatures of the oil slick. The exploratory work to date shows that ability to detect oil slicks increases with decreasing wavelengths. It also shows that sea state increased the brightness of the oil slick, a phenomenon not observed in laboratory tests in calm water. The effects of temperature on detectivity and the influence of various sea states on the data are questions which must be answered in future work.

In summary, microwave radiometers appear to offer a promising means of detecting, measuring the thickness of, and tracking oil spills in the open ocean, on an all weather, day and night basis. However, care must be taken in applying these techniques, since it is possible to obtain combinations of oil thickness, incidence angle, and wind speeds that could change the nature of the signature or render spills invisible.

4.3.6 Data Presentation

The display of pollution data in a meaningful format that can be readily assimilated into a water quality system is mandatory. A preliminary attempt to accomplish this has been made by TRW, (8) using data acquired by a spectrophotometer (WISP) and a water color spectrometer (WCS), both operating in the visible spectrum, off the coast of Santa Barbara, California. Their method was to utilize a computer to generate a map of water pollution concentration. The computer inspects the individual spectral reflectivity curves recorded during a WISP flight and by making some simple comparisons of the relative reflectivity in certain selected regions of the spectrum, the computer assigns an estimate of the pollution concentration to each point in the water. The computer then prints one of a group of previously selected symbols representing varying density corresponding to the relative concentration of pollution in the water.

A logical upgrading of this technique, which will be implemented into TRW's system in the near future, is to use a high speed digital plotter to plot and connect lines of equal spectral characteristics in the water. A contour map of water pollution, water color variation, etc. can be easily generated in this manner.

Additional data presentations produced by TRW using WISP data were produced by comparison of the spectrums of the oil slick and of blue water. Figure 4.3-4 shows the spectra for the two runs normalized to the same level and plotted with arbitrary units along the ordinate.

A comparison of the blue water and oil slick curves may be made on the basis of the WISP spectral calibration. The blue water curve peaks in band 17-18 (4800-5000 Å). The oil slick curve peaks in bands 15-17 (5000-5300 Å). It may be seen in bands 18-20 that the amplitude of the oil slick curve falls off much faster than does the blue water curve.

The amplitude of the oil slick curve is as much as 25% larger than the amplitude of the blue water curve in bands 7-13, if the DC level is regarded as a zero reference for the spectral curves. Throughout the entire range of bands 2 thru 17, the oil slick curve exceeds the blue water curve, indicating a larger red-orange-yellow-green spectral content.

A comparison of spectral reflectivity curves obtained from spectrometer (WCS) data showed an increase concurrently with a change in water color from blue to red (see Figure 4.3-5). Water samples collected simultaneously not only substantiate the color change but found the cause to be red tide, a large concentration of dinoflagellates.

4.3.7 Conclusions

Before any remote sensing techniques for pollution detection can be considered operational, extended and detailed investigations into the nature and interaction of numerous environomental and physical parameters of a pollution/sea system are needed. The availability of proper sensors is also crucial to the effectiveness of any aircraft or spacecraft system for detecting pollution and additional development remains to be done.

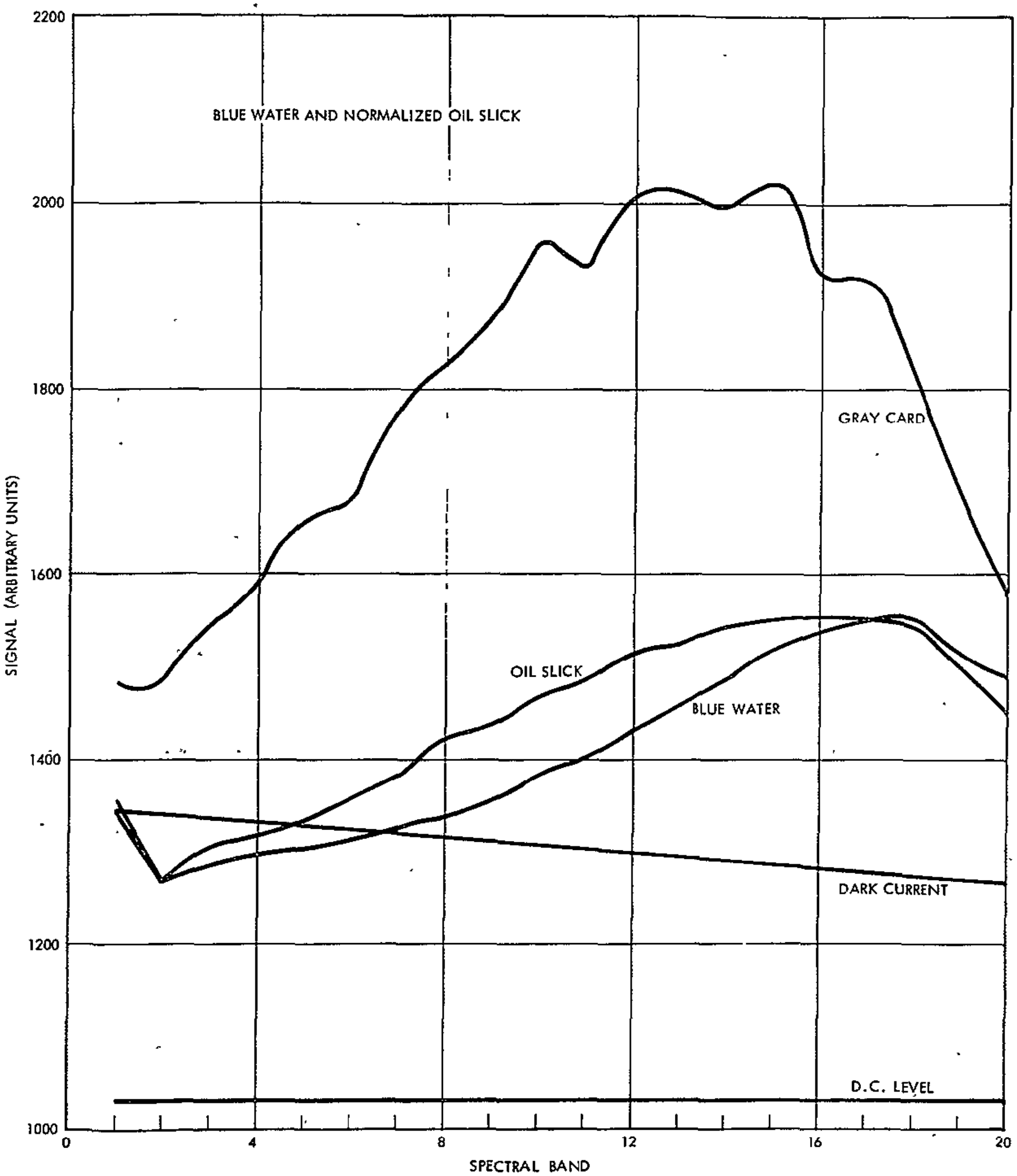


Figure 4.3-4 Normalized Blue Water and Oil Slick Curves (8)

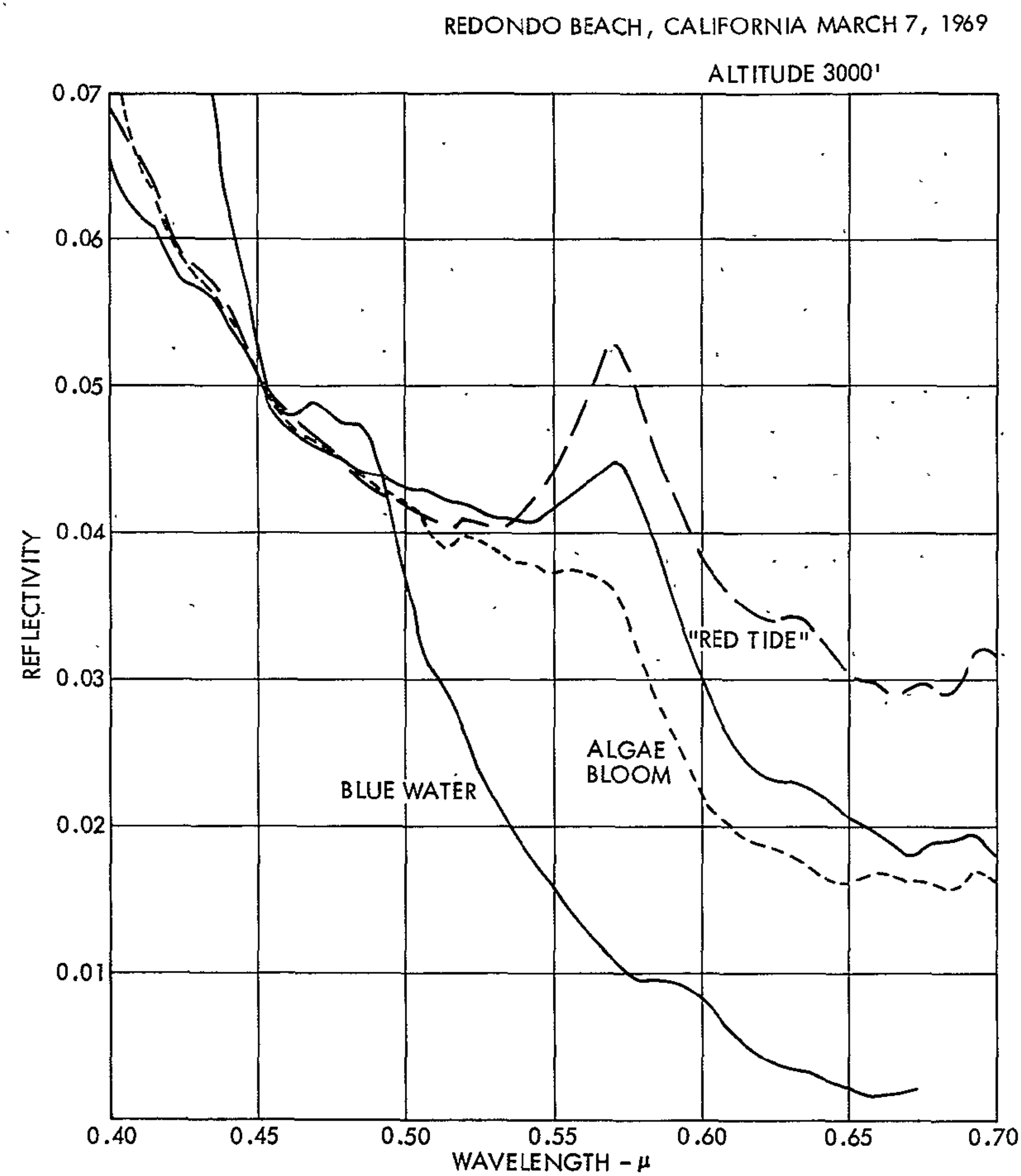


Figure 4.3-5 Spectral Reflectivity of Different Areas of Sea Water (8)

Most of the studies that have been conducted relate to oil pollution. The best definition of oil slicks has been in the 8-14μ thermal IR region; although data in the ultraviolet, visible, and microwave regions also exhibited strong anomalies over oil. Analyses of data acquired in the visible region by various investigators provided slightly conflicting data pertaining to contrast of oil slicks in the red spectrum. Additional airborne studies, with surface truth data also being acquired, should clarify this disagreement. As for the use of microwave techniques, it must be determined whether factors such as foam, salinity, atmospheric absorption, rain scattering, and waves cause specular obscuration of ocean-emitted microwave radiation that would make it impossible to obtain unambiguous measurements of oil slicks and other surface phenomena.

In consideration of these results for the remote detection of pollutants, it appears that the potential for providing important information from either air or spaceborne sensors is significant.

4.4 SEA SURFACE TEMPERATURE

4.4.1 Introduction and Background

Sea surface temperature has been that oceanographic parameter that has received the most extensive study using space acquired data. Sea-surface temperature (SST), as measured by an infrared radiometer, is the temperature of the surface layer of the ocean, less than 1 mm in thickness. Because of the stirring processes occurring at the sea surface, this temperature seldom differs by more than a few tenths of a degree centigrade from the bulk temperature of the surface layer, and most presentations of sea-surface temperature pertain to measurements made at various depths in the upper few meters. This variable is of fundamental importance in the thermodynamics of the upper ocean and lower atmosphere and their interaction and thus enters into predictive models for both systems.

Charts of the sea-surface temperature are widely used for a number of purposes, including studies of energy exchange at the sea surface, studies of surface circulation (location of current boundaries), studies of biological productivity (location of upwelling areas), and studies of the biological environment. Such studies are of demonstrable importance to fisheries (distribution, abundance, and availability of fish), meteorology (long-range weather forecasting), coastal engineering (pollution, river outflow, and sewer effluent), and shipping (location of major currents) as well as to physical and biological oceanography.

The remote sensing of SST has been under study for a number of years using both aircraft and spacecraft as platforms. The technique has also been utilized on an operational basis from aircraft using the airborne radiation thermometer (ART) as the sensor. Some of the more significant results will be summarized in this section.

4.4.2 Spacecraft Data Acquisition Systems

A number of investigators (37, 38, 146) have analyzed a considerable amount of infrared data acquired by the various meteorological satellites (TIROS, ESSA, and NIMBUS) to assess their applicability for sea surface temperature determination. Table 4.4-1 lists these satellites along with

TABLE 4.4-1

SATELLITES WITH INFRARED AND AUXILIARY SENSORS (52)

Satellite	Data Mode	Sensor	Launch Date	End Operations	Operational Period	Orbit	Inclination (°)	Apogee[1] KM. (NM.)	Perigee[1] KM. (NM.)	Average[1] Altitude KM. (NM.)	Total Pictures[2] or Picture Rate	Picture[3] Resolution KM. (NM.)
Nimbus 1	Infrared	HRIR	8/28/64	9/23/64	26 Days	Polar	98.7	922 (503)	423 (228)	678 (366)	6,000	8 (4.3) AT 925 (499)
	TV	AVCS		9/23/64	26 Days						12,000	0.9 (0.5) AT 925 (499)
Nimbus 2	Infrared	HRIR	5/15/66	11/15/66	174 Days	Polar	100.3	1,179 (636)	1,095 (591)	1,137 (614)	N.A.	9 (5) AT 1,100 (595)
	Infrared	MRIR		7/28/66	75 Days						N.A.	56 (30) AT 1,110 (600)
	TV	AVCS		8/31/66	109 Days						114,000	0.9 (0.5) AT 1,100 (595)
Nimbus 3	Infrared	HRIR	5/14/69	Operational	Continuous	Polar	81.0	1,132 (612)	1,071 (571)	1,001 (541)	N.A.	9 (5) AT 1,100 (595)
	Infrared	MRIR		Operational	Continuous						N.A.	56 (30) AT 1,110 (600)
	TV	IDCS		Operational	Continuous						N.A.	0.9 (0.5) AT 1,100 (595)
ITOS	Infrared	HRIR	1/17/70	Operational	Continuous	Polar				~1,435 (775)		
	TV	AVCS		Operational	Continuous							
Nimbus 4	Infrared	THIR (Temp.)	4/8/70	Operational	Continuous	Polar				1,110 (600)		9 (5) AT 1,100 (595)
	Infrared	THIR (Hum.)		Operational	Continuous							12 (15) AT 1,110 (600)
	TV	IDCS		Operational	Continuous							0.9 (0.5) AT 1,100 (595)

FOOTNOTES:
1. Values are not meant for scientific purposes; they should be used only as a guide to the size and shape of orbit.
2. Where applicable, total number of pictures is cited for those satellites which were no longer in operation on 31 December 1968. Picture rate (time needed to take one picture) is cited for operational spacecraft.
3. Where values are applicable, resolution is measured at the subsatellite point. For example, the Nimbus 2 HRIR at an altitude of 1,100 KM. (595 NM.) has a subsatellite ground resolution of 9 KM. (5 NM.).

N.A. = Not Applicable

pertinent information (52). To date, only the Nimbus 1, 2, and 3 satellites have provided infrared data with the resolutions useful for preliminary oceanographic SST studies. Also, certain anomalous dark areas in sunglint patterns are occasionally seen in photographs taken by the ATS (13). These dark areas appear to be caused by relatively calm surface conditions against a background of higher sea states. Evidence of cold water temperatures in the dark areas suggests the presence of upwelling. More recently, ITOS and Nimbus 4 have been launched and are expected to provide valuable SST data for oceanographic research; however, as of this writing, definitive results have yet to be realized.

4.4.2.1 Nimbus Data for Sea Surface Temperature Determination

Two infrared sensors of potential value to oceanographers were onboard the Nimbus 1, 2, and 3 satellites. The sensor most useful was the High Resolution Infrared Radiometer (HRIR), a scanning radiometer, operating in the 3.4 to 4.2 micron atmospheric "window" region. This instrument provided resolutions of 3^{o} - 4^{o}C or better, depending on corrections applied and ~10-12 km (spatial). The objective of this instrument was to provide both daytime cloud mapping and nighttime radiation measurements.

The second infrared sensor, a Medium Resolution Infrared Radiometer (MRIR), was a five-channel scanning radiometer, operating between 0.2 and 30 μ, designed to measure electromagnetic radiation emitted and reflected from the Earth and its atmosphere. A variety of information was obtained from each of the channels as well as from a combination of channels.

The MRIR's resolution was much coarser than that of the HRIR. For example, at an altitude of 1,000 km, the 10 to 11 micron channel had a temperature resolution of ~7^{o} C and a spatial resolution of 55 km at zero nadir angle. Recent work has shown that despite the MRIR's lower resolution it is possible to derive such information as sea surface temperature from the data, if the region is cloud-free and the projection scale used is approximately 1:5 million or greater.

The Nimbus satellites circled the globe in a polar orbit, their sensors constantly oriented to the Earth and their periods timed to always provide

satellite passage at approximately local midday on the Earth's lighted side and at local midnight on the Earth's dark side. Thus, each point on the Earth's surface is viewed at least twice a day by the satellite. Overlaps in the satellite coverage increase toward higher latitudes with each of the poles being viewed fourteen times in twenty-four hours.

General conclusions of investigators who have made studies of Nimbus IR data indicate the feasibility of acquiring SST from operational meteorological satellites. In a study conducted by Wilkerson and Noble (151), they acquired synoptic measurements of the SST field of a 10 x 20 degree area of the North Atlantic by Airborne Radiation Thermometer (ART) and shipboard bathythermographs (BT's). These data were then used for ground truth for the interpretation of Nimbus II HRIR radiation temperature observations.

Table 4.4-2 presents the results of the comparison of the ship and aircraft data with the Nimbus II radiation temperature data (151). Surface temperature data from 64 BT casts, taken between 15 and 18 June 1966, were compared with the corresponding satellite grid-point data. Comparison of the average temperature values from the two sets of data showed that the satellite radiation temperatures were biased 3.6° C higher than the ship obtained surface temperature data. Upon removal of the 3.6°C bias from the satellite data, there remained a mean absolute error of 1.5° C between the ship and the satellite data.

Comparison of the satellite and the aircraft data showed the satellite data to be biased 2.4°C higher than the aircraft data. Removal of the bias from the satellite data results in a mean absolute error of 2.0°C between the satellite and aircraft data. One hundred and thirty-four one minute averages of the ART record were compared with the corresponding grid-point data values.

The primary sources of bias and mean absolute errors between the satellite radiation temperatures and the conventional sea surface temperatures are instrumental noise, atmospheric absorptions, computer averaging of the resolution elements into the grid-point values, extraneous reflections of solar radiation into the radiometer windows, and field contamination by subresolution element clouds. The instrumental system errors in the satellite radiation temperatures have been discussed by Warnecke, McMillin, and Allison (145).

TABLE 4.4-2

COMPARISON OF SHIP AND AIRCRAFT SST WITH NIMBUS II HRIR DATA, 22 JUNE 1966 (151)

Ship vs HRIR, 15-18 June 1966 64 points		ART vs HRIR 21 June 1966 134 points	
Avg. Temp., Ship Data	23.5°C	Avg. Temp., ART Data	22.8°C
Avg. Temp., HRIR Data	27.1°C	Avg. Temp., HRIR Data	25.2°C
Temp., Bias	+ 3.6°C	Temp., Bias	2.4°C
Mean Absolute Error, Ship vs HRIR	3.94°C	Mean Absolute Error, ART vs HRIR	2.94°C
Mean Absolute Error, Ship vs HRIR (Bias subtracted from HRIR data)	1.5°C	Mean Absolute Error, ART vs HRIR (Bias subtracted from HRIR data)	2.0°C

The magnitude of the sea surface temperature gradients associated with the Gulf Stream boundary which have been defined range from a maximum of 6° C/600 meters from the analog ART data, to 5° C/11 kilometers from digitized HRIR data to 5°C/110 kilometers using Fleet Numerical Weather Central computer analyses. The difference in resolution between these analyses provide a measure of sea surface temperature analysis improvement potentially available through the increased synoptical data coverage afforded by satellite.

4.4.2.2 Nimbus Data Handling

HRIR and MRIR data have been processed for display to provide output in two forms: a digital form for quantitative analysis; and an imagery form, similar to television pictures, for comparative studies.

The areal coverage of the surface of the oceans by the HRIR and MRIR data was limited by the amount of cloud cover. This interruption by clouds is normally obvious in the data when the cloud temperatures are low. However, because the HRIR data were collected at night and the MRIR's resolution was low, it is sometimes difficult to differentiate between low clouds and the sea's surface when their radiational temperatures are simliar. Useful HRIR digital data were limited to those data collected during the night since the daytime measurements had reflected solar radiation added to the Earth's infrared emission.

In the examination of single-day HRIR data it is necessary to use clear-sky data. Such information is possible by assigning threshold temperature values high enough to guarantee the exclusion of cloud data. Since some sea surface temperature information may be lost by this method, a second procedure of examining single-day data was used. This method utilized a minimum threshold grid made of historical minimum temperatures to exclude cloud data. (A maximum ceiling made of maximum temperatures may also be used to help exclude the more obvious of the electronic "noise"). Both of these methods are difficult to use in analyzing high altitude data where cloud and water temperature values are similar.

A method formulated by La Violette and Chabot (54) to remove transitory clouds artificially from the HRIR data involves a highly selective composite

of several days' data. An example of this compositing is shown in Figure 4.4-1. The HRIR data for the region for each day were printed by computer using a Mercator projection of 1:2 million scale. The mesh size of the data printout at this scale formed the resolution of the study. The printed temperature value for each day for each point was an average of ten HRIR scan spots and represents an approximate area of 497 sq. km within the nadir angle limitation of 50°. The temperature printed was a "corrected average" determined by excluding from the average all data lying outside boundary temperatures based on historical extremes.

The five-day composite, called a High Daily Average (HDA) composite, was made by examining the daily temperature average at a point for each of the five days, and printing the highest daily average which occurred during the period. This process was repeated for the entire HDA chart. The resulting printed values were designed to reflect either no clouds or the smallest concentration of clouds over each point for the five-day period.

Because of these inherent problems computer recognition and elimination of cloud contaminated data points is called for. The radiance contrast, in the visible and the IR, between an extensive thick cloud deck and a large clear region is readily discernible in present satellite data. However, this radiance contrast can provide no clear indication of the effects of thin cirroform clouds, or of situations involving scattered cumulus in which the sensor resolution element is only partially filled by clouds. With the data presently available, the identification of these situations is not always possible.

In order to optimize the techniques of using simultaneous measurements in different spectral regions, threshold values for cloud contamination must be established. To accomplish this, the characteristics of the transition between clear and cloudy areas must be better understood. A clear distinction in radiance between cloudy and clear atmosphere does not exist in any wavelength region. However, the trade-off between useful sea surface coverage and the false alarm rate can be optimized if the radiance characteristics of clouds can be determined.

In order to improve current knowledge of these radiance characteristics, interest must be selectively focused on special cloud cover situations. Since

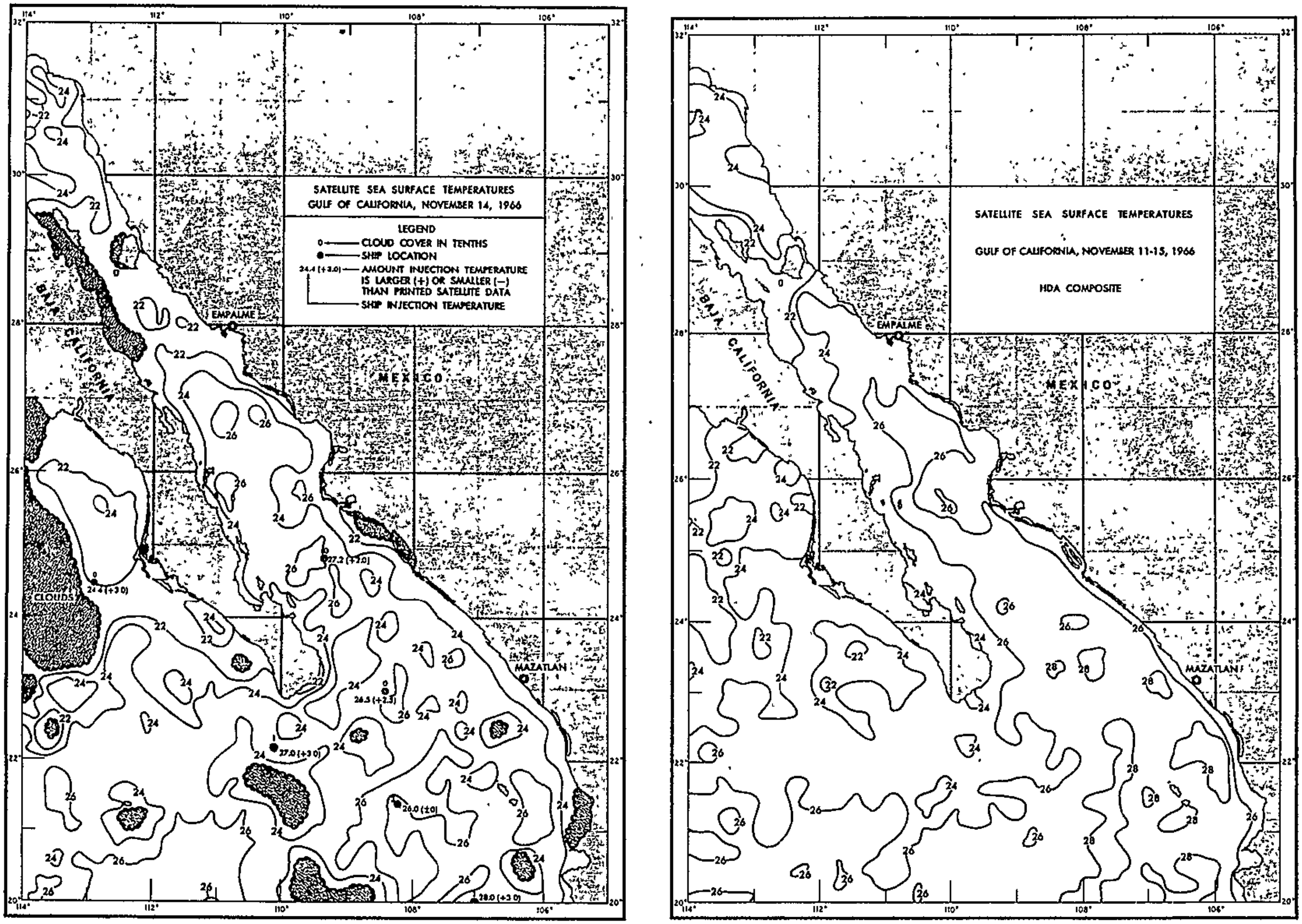


Figure 4.4-1 A study of sea surface temperatures in the Gulf of California using satellite infrared data - Nimbus 2

Five days of High Resolution Infrared Radiometer (HRIR) data, 11 through 15 November 1966, were examined individually and then combined in a selective composite designed to arrive at sea surface temperatures in a region of transitory clouds. An examination of the individual charts showed a small migration of warm water northward into the Gulf during the five-day period. The variation was small however, and the five-day High Daily Average (HDA) composite may be taken as representing the sea surface temperature conditions of the region with the transitory clouds removed.

(LaViolette and Chabot 1969) (54)

these phenomena are essentially targets of opportunity, it would be desirable that measurements and observations be performed by means of a manned spacecraft system.

4.4.2.3 Potential of ITOS and Nimbus IV Sensors

Even though definitive results are yet to be realized utilizing Nimbus IV or ITOS data for oceanographic applications, short descriptions of their potential will be given.

Nimbus IV is the most recent satellite in a series of advanced research and development weather systems and carries, among other instruments, a Temperature Humidity Infrared Radiometer (THIR). This instrument along with the Scanning Radiometer (SR) aboard ITOS (ESSA's Improved Tiros Operational Satellite) have a significant potential for measuring sea surface temperature. However, because the instruments are meteorologically oriented there are certain inherent difficulties in utilizing the sensors for oceanographic measurements. One of the largest difficulties is the atmospheric moisture effect on infrared sensor recordings of the ocean's surface blackbody radiation. When clouds are present between the sensor and the ocean, the sensor records the cloud rather than the ocean's radiation temperatures. Thin clouds or smaller amounts of moisture also affect infrared sensor data by making the ocean's surface appear cooler than it actually is. The amount of cooling is directly proportional to the amount of water vapor in the air.

Both instruments, the THIR and SR have infrared channels which operate in the 10.5 to 12.5 μ range, beyond the range of reflected sunlight. This is significant because SST data can then be collected from both day and night sides of the Earth without reflected sunlight influencing the return. This channel did not exist on prior high resolution radiometers flown on Nimbus. Whether data collected from the day side will be representative of sea surface temperature is a matter that must be examined during the initial inflight calibration of the first ITOS satellite.

Sea surface temperature data acquired by infrared sensors are actually the blackbody radiation of the first millimeter of the surface. Nimbus' night data have been acceptable because sufficient radiation loss is believed to have occurred by midnight, so that the surface represents a dynamic mixing to a

depth of at least three meters. During the daytime, insolation offsets the radiation loss by a variable amount. If there is no mixing, such as when wind speeds are less than 10 knots, then the day-time measurements of ITOS may be the radiation of a surface film several degrees warmer than the water a few centimeters deeper. It is doubtful that this limitation will have a great effect on the usefulness of ITOS's "second look." The ability to study diurnal differences in ocean surface temperatures and to distinguish cloud regions clearly will be a great asset to the sensor's oceanographic capability.

The infrared channel's noise equivalent temperature difference is expected to range from 1°C for a 27°C scene to 4°C for a -88°C scene. Sea surface temperature resolutions achievable using a radiometer designed expressly for that purpose would be substantially improved. This results primarily from the temperature range of interest being much narrower, -5°C to +35°C, thus allowing, for example, sensitivity to be increased and much less complicated cooling devices.

4.4.3 Aircraft Data Acquisition

Various IR radiometric techniques for the measurement of sea surface temperature have been used from aircraft, on an operational basis, for the past few years. A number of government agencies as well as private companies are included; for example, Navy, Coast Guard, NASA, BCF and USGS. The present research activities relate to determining precisely how surface temperature relates to other oceanic phenomena such as fish, currents, pollution, etc., so the data can be efficiently and effectively utilized. Research in these areas of application can be found in those sections discussing the specific ocean phenomenon.

4.4.3.1 Airborne Radiation Thermometer (ART) Studies

The airborne infrared radiation thermometer (ART) operates in the 8-13 μ region of the spectrum and uses a thermistor bolometer detector. From an altitude of 300 meters, the instrument views a 12 x 12 meter spot along the flight path beneath the aircraft. The instrument is calibrated over the range of -2° to +35°C to an accuracy of ± 0.2°C. However, atmospheric conditions can lead to errors of as much as several degrees centigrade in recorded temperatures. Corrections have been developed which give the instrument a field accuracy of ± 0.4°C ninety-five percent of the time (90).

Significant scientific results have been obtained using this instrument. For example, in 1967, Wilkerson (150) using data acquired on the Gulf Stream noted the formation of a cyclonic eddy south of the Gulf Stream. These data were the first to be remotely acquired showing such a phenomenon. Data have also been acquired over Lake Michigan (88), with various surface water thermal gradients being observed.

4.4.3.2 Utilization of Cloud Field

Various investigators have studied the possibility of correlating cloud patterns observed from weather satellites with sea surface-air temperature differences existing at sea level. The assumption is that information on air-sea temperature differences is provided by the presence or absence of cumulus type clouds on relatively clear days.

Arnold (3), Maughan (61), and other investigators (83) have found that sea surface temperatures could be postulated for areas below cumulus type clouds. Further, it was shown that cool water below warm air displayed an absence of cumulus type clouds and warm water below cool air expressed itself by the formation of cumulus type clouds. However, the technique was found to be impractical, overall, in view of the dependence of the cloud field on several parameters in addition to SST. When frontal systems, atmospheric motions, and land radiation influence cloud patterns, it is evident that low level clouds are masked. Under these conditions, postulating SST using cloud patterns becomes impractical.

4.4.3.3 Microwave Radiometric Studies

Studies to obtain sea surface temperature, using passive microwave techniques, have been conducted in the laboratory, remotely from the surface and from low flying aircraft (5, 30, 92). A number of investigators and research establishments are using various instruments operating over a wide range of frequencies, 1 GHz to 90 GHz. A general conclusion is that a significant amount of additional information needs to be obtained prior to making any decisions on the value of the technique.

Aside from roughness, microwave emission characteristics of water depend on water temperature and salinity. Investigators at Texas A&M University (92, 93) have computed the emissivity and absorption of sea water as a function of wavelength, salinity, water temperature, and dissolved gases. These data are expressed as the product of the computed emissivities and physical temperatures. Changes in salinity have little effect above about 8 GHz ($\lambda = 3.75$ cm) and the higher frequencies exhibit a nonlinear water temperature dependence. A frequency of 4 GHz ($\lambda = 7.5$ cm) was deemed optimum for linear response to water temperature in areas having salinities of roughly 35 o/oo. With salinity variations over a wider range, a frequency of 6 GHz ($\lambda = 5$ cm) was deemed optimum.

Theoretical data also indicate that microwave sensors should be most responsive to water temperature variations for observational wavelengths near 5 cm, where the dependence is substantially linear. At this wavelength, and for moderate viewing angles where atmospheric path lengths are minimal, ocean water exhibits an emissivity of about 0.4. Thus, a 20° C change in water temperature would result in a change in brightness temperature (T_B) of about 8°K, and water temperature variations of the order of a few degrees will result in very slight T_B changes. On the open ocean, these small changes are apt to be masked by contributions associated with surface roughness and weather.

Laboratory data measured at 37 GHz ($\lambda = .81$ cm) and 13.4 GHz ($\lambda = 2.2$ cm) (30) show good agreement with the Texas A&M results. These measurements were obtained in an environmental chamber where the water was cooled at a slow rate. The antenna viewing angle was 30°. The data indicate only slight changes in the brightness temperature (T_B) for a relatively large range of water temperatures. Additional data will be acquired (30) using a wider selection of radiometers including observational wavelengths of 0.8 cm, 2.2 cm, 6 cm, and 21 cm.

For these reasons it does not appear practical, with present state of the art, to measure ocean surface temperature from spacecraft or high altitude aircraft by means of microwave radiometry, for even at low frequencies and under ideal conditions, SST could only be determined in those areas where strong surface gradients exist.

In order to extend the state of the art of microwave techniques, J. Paris (93) has specified the following problems that need attention:

(1) The complex dielectric constant of sea water needs to be determined accurately for a number of temperatures, salinities, and frequencies.

(2) More airborne measurements are needed in the L-band and S-band.

(3) The effects of multiple scattering must be determined for a large range of meteorological conditions.

(4) The effects of foam need to be determined quantitatively through well-supported aircraft measurements.

4.4.4 Conclusions

The measurement of sea surface temperature using IR techniques from both aircraft and spacecraft is well within the state of the art and is more or less operational from aircraft. It appears that an IR radiometer, designed expressly for SST measurements and using current state of the art capabilities, could acquire temperature data with a resolution of $1^{\circ}C$ from space.

Present attempts to map SST using meteorological satellites have been frequently hampered by light clouds. Multiple passes by a satellite such as Nimbus permit some cloud cover removal for surface observations due to the randomness and movement of clouds. However, the longer the observation period needed to remove cloud cover, the greater the loss in the observation of dynamic thermal features. Hence, the need for all weather systems have already been demonstrated.

The feasibility of using microwave radiometric techniques for these measurements, however, still remains to be determined. This results from the fact that variations in emissivity in the microwave region, for example surface roughness related to sea state, may completely mask thermal changes. It is anticipated that microwave thermal mapping can be accomplished only when a solution is found to sea state measurements. Numerous studies are directed to seeking all-weather solutions to these problems. Use of dual polarization, fixed angle of incidence, antenna systems, combinations of both active and passive sensors, and potential use of dual frequency systems are being investigated.

In conclusion it appears that IR techniques are the best suited for operational systems in the near future, at least until the feasibility of microwave techniques can be determined.

4.5 SEA STATE/WIND

4.5.1 Introduction

The prediction of ocean wave spectra permits the efficient routing of ships to allow them to travel faster and prevent excessive storm damage. Wind information is a vital part of both weather prediction and ocean wave prediction. The relationship between wind speed and radar scattering cross section may provide the opportunity to use a spaceborne radar system to obtain wind information over those extensive areas of the oceans where ship reports are too sparse for accurate forecasting. When atmospheric radiation and attenuation are not too great, a microwave radiometer is also sensitive to wind speed. Since the effective temperature seen by the radiometer is strongly dependent on attenuation in the atmosphere, the radiometer can be used to provide a correction to the measured radar backscatter signal.

Prediction of ocean wave spectra involves knowledge of the surface wind field over a large area and long time intervals. Waves can propagate over large distances, and the effect of local winds is felt for many hours after the winds have died down. Hence, the numerical prediction techniques depend on an iterative solution of the appropriate equations over the period of about a week. Updating at intervals of about six hours permits the predictions to be continuously extended. The grid for numerical forecasting cannot be too fine, or it would require too much computer capacity; accordingly a 120 km point spacing has been proposed (68). Fortunately this will permit a satellite instrument to operate with a resolution of tens of kilometers, which greatly simplifies its design.

4.5.2 Radar Observations of Ocean Backscatter

From preliminary radar observations of ocean backscatter, an increase in off-vertical radar backscatter with increasing "sea state" has been observed. Attempts have been made to relate this phenomenon to both wave height and wind speed; but in recent years it has become apparent that wind speed is more important in determining radar return than wave height, at least for most angles of incidence and for microwavelengths. This is probably due to the strong dependence of the radar return on the high-wave number part of the ocean wave spectrum (i.e., the small structure), and the dependence in turn of this part of the wave structure on the current local wind (67, 68).

Various observers have indicated some sort of "saturation" in the increase of radar return with windspeed. The validity of the observations of saturation seems to be dependent on radar wavelength and on the approximations in radar theory. Evidence reported by Moore and Pierson (67, 68) indicates no saturation for the 2.25 cm radar wavelength up to wind speeds between 40 and 50 knots, whereas saturation does appear at much lower windspeeds for 75 cm radar waves. The NRL measurements at 3.3 cm show a much smaller variation with windspeed, and measurements at longer wavelengths show almost no increase in radar return at midangles for wind speeds above about 12 knots.

A NASA/MSC aircraft made 2 flights over the North Atlantic, one in the spring of 1968 and one in the spring of 1969. Two radar scatterometers were carried on these missions, one at 2.25 cm radar wavelength (both missions) and the other at 75 cm radar wavelength (1969 mission only). During the 1969 mission essentially simultaneous radiometer measurements were made at 1.6 and 3.2 cm by Nordberg of NASA/GSFC, using NASA's CV-990, (30). Because the relative measurements are much more accurate than the absolute measurements, the 2.25 cm observations have been normalized to 10°. Figure 4.5-1 shows the normalized 2.25 cm upwind measurements for a variety of windspeeds and for runs made during both years. The effect of the normalization is to make the ordinate the ratio of the differential scattering coefficient (σ^{o}) at each angle to that at 10°, expressed in dB. Clearly, the normalized value of σ^{o} increases with increasing wind speed for all angles above 10°. The difference between the two curves for nearly equal lower wind speeds has not been explained, but may be due to the effect on one of them of a confused sea.

The difference between upwind and crosswind data is indicated in Figure 4.5-2. Not only are the crosswind values less, but their variation with windspeed is different from that for upwind data.

Observation of Figures 4.5-1 and 4.5-2 might lead to the conclusion that saturation is indeed occurring, however, this is actually an illusion caused by use of the logarithmic dB scale. When logarithmic scales are used for both wind speed and σ^{o}, the scattering continues to increase up to the maximum wind speed for which observations are available.

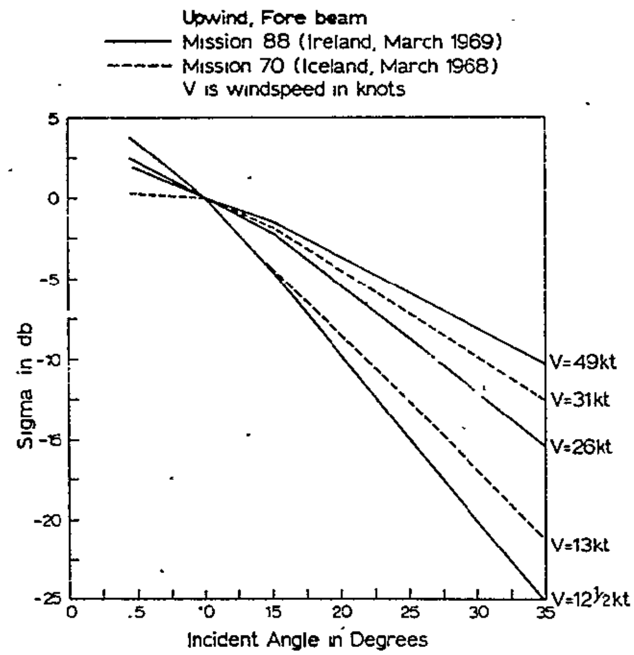


Figure 4.5-1. Differential Scattering Coefficient of Ocean at 2.25 cm Wavelength Normalized to 0 dB at 10°. (68)

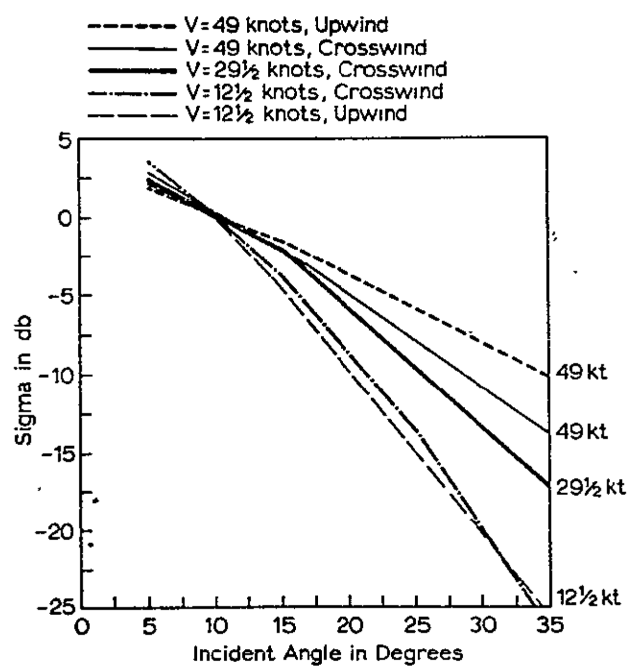


Figure 4.5-2. Comparison of Crosswind and Upwind Data, Mission 88 (Ireland, March 1969). (68)

From these results, the use of radar cross-section as a measure of wind speed appears feasible, provided the wind direction is known. On the basis of the relative measurements, a system based on measurements at two angles (say, 10° and 35°) along the satellite ground track can be justified. The general conclusion that can be drawn from both previous measurements and theory is that the curves of absolute magnitude of the differential scattering coefficient should cross each other in the vicinity of 10°, as do the normalized curves.

The measurements made at the 75 cm wavelength show, if anything, a reverse trend with respect to wind speed, but this trend is small enough to be due to measurement error. Figure 4.5-3 illustrates a comparison of the results at 2.25 cm and 75 cm, with only the limits of the 2.25 cm observations shown to compare with three representative curves for 75 cm. Since no back-scatter can occur for a perfectly smooth ocean, the 75 cm scatter must saturate somewhere in the neighborhood of 12 knots, for measurements at much lower wind speeds would have to fall below those for 12 knots (at higher incident angles). Because of this saturation at low wind speeds, 75 cm appears not to be useful for satellite determination of wind speed, except perhaps for very low winds. Guinard's (40) 3.3 cm measurements show the same trend as the 2.25 cm NASA results, but with much less sensitivity to wind speed. Thus, it appears that proper choice of frequency for radar determination of wind speed is very important.

4.5.3 Microwave Radiometric Measurements of Sea and Precipitation

Although microwave radiometric observations of relatively calm seas and of controlled surfaces have been available for some time, measurements of microwave brightness temperature of the ocean under high sea state conditions appear to have been made for the first time during 1969 by Nordberg, (30) and Blinn (11). These measurements were also made over the North Atlantic and include the same points as the radar measurements discussed previously.

These experiments, include measurements with a 1.55 cm microwave imager and with a 3.2 cm radiometer. During these flights, sea states were observed corresponding to surface winds ranging from 10 knots to 58 knots. Considerable data were obtained over very rough seas whose characteristics ranged from deep swells with long fetches to violent, wind-driven seas with

very short fetches. Wave spectra of the sea surface were obtained with a laser profiler onboard the CV-990. The effects of clouds which ranged from low altitude, thin stratus to thick overcast with occasional cumulus buildups and rain cells, were also measured.

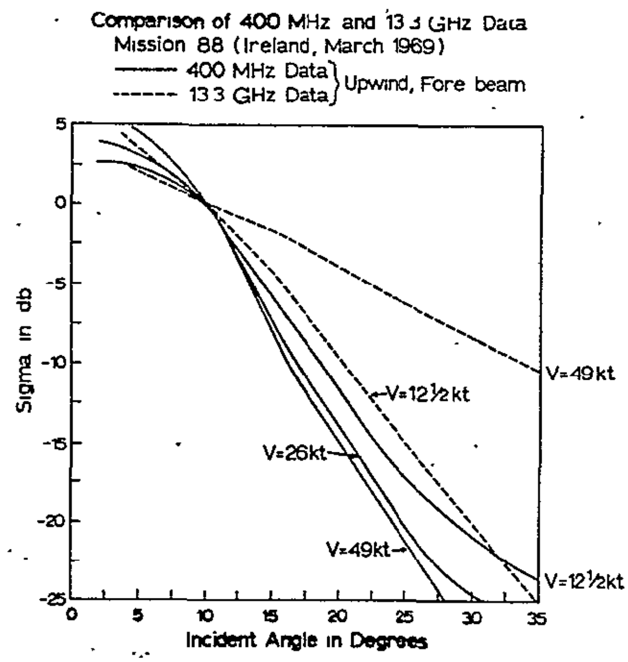


Figure 4.5-3. Differential Scattering Coefficient of Ocea
Normalized to 0 dB at 10°. (68)

The effective temperature of the surface, measured with the radiometer at the 3.2 cm wavelength, increased from about 105° to about 125°, over a wide range of sea conditions from less than 12 knot winds to over 50 knot winds.

The strong dependence of 1.55 cm emission on sea surface roughness, originally observed over the Salton Sea (30) was confirmed. Over smooth sea, (10-14 knot winds) brightness temperatures of about 115° to 120°K were measured. Over rough seas (35 to 40 knot winds) brightness temperatures of about 140°K were measured.

At windspeeds greater than 40 knots, an interesting situation arises. The same brightness temperatures were measured for windspeeds of 37 knots over a fully developed sea in the North Atlantic and for the North Sea at 55 knots.

A laser profilometer, carried on board to provide surface truth data, indicated average wave heights of 5.4 to 7.5 m respectively for these two conditions, and vastly different wave spectra for the two seas. This was also reflected in the instantaneous values of 1.55 cm microwave emission in the presence of high wind conditions. The fully developed sea with lower windspeeds showed fewer and much smaller fluctuations around the average brightness temperatures of 140°K. The wind-driven sea at 55 knots and 40 knots showed frequent excursions to brightness temperatures much higher than the average. In some instances, these excursions reach brightness temperatures of 200°K. From sea surface photographs and other simultaneous observations, these excursions can be correlated with large (15-30 m) patches of foam on the sea surface. These foam patches exhibit very high emissivities or brightness temperatures which are observed only when the radiometer beam scans over their areal extent. Between the patches, the sea did not produce any higher emissivities than for the 37-knot case. When the aircraft was at higher altitudes, the individual foam patches could not be distinguished and the radiometer's instantaneous response assumed a characteristic and an average brightness temperature similar to that for the 37-knot wind case. These observations are in line with Williams' (153, 154) experimental results of sensing foam in a tank of water, Hollinger's (45) results at Argus Island and also Aukland's (5) results. In addition, Hollinger found that the surface disturbance due to rain has much less effect on the emissivity of the sea than does foam.

These data, acquired with the 1.55 cm imager, indicate that sea surface emission corresponds rather well to the wave heights, at least up to about 6 m. However, it does not relate to windspeeds, especially for very strong winds. The observations with the 3.2 cm radiometer seem to indicate that, at that wavelength, the same effect exists qualitatively, but quantitatively it is somewhat smaller. Effects of clouds (negligible for thin stratus, but considerable for rain cells) at the 1.55 cm wavelength were confirmed in all flights. The cloud/rain effect is much less at 3.2 cm.

Results from preliminary analyses of data acquired from the 9.3 GHz radiometer are as follows (11):

1. The microwave temperature of the ocean varies less than $10^{\circ}K$ for wind speed changes from 0 to 30 kts. Part of this $10^{\circ}K$ differential may be due to undetermined variations in sky brightness temperature.

2. Foam does not have the strong influence at this frequency as it does on other frequencies.

3. Using a simplistic model, sky brightness temperatures of 15.5 and $21.8^{\circ}K$ were predicted for stratus clouds approximately 14,000 feet thick. This indicates that clouds have a significant effect at 9.3 GHz and must be accounted for if meaningful measurements are to be made over the ocean at this frequency.

Additional experiments are in progress (118) to clarify the physics of microwave emission associated with the sea surface roughness. These include analysis of 0.81 and 1.55 cm data gathered during recent CV-990 flights in the Caribbean near Barbados, flights off the Southern California coast and additional multiwavelength dual polarized measurements (λ = 0.8, 2.2, 5 and 21 cm) of near shore wave conditions. Other experiments planned in the near future include stationary measurements from the Argus Island Tower (NRL) and multi-frequency measurements over the Atlantic (NASA/MSC).

More data, preferably multiwavelength, are needed to clarify contributions from small and large scale roughness. By proper choice of sensor characteristics (wavelength, polarization, and viewing angle), it may be possible to distinguish between emission associated with the two types of roughness and to develop a practical means of determining sea state by passive microwave techniques. Multispectral methods may provide the solution.

4.5.4 Laser Profiling of the Sea Surface

In addition to the potential use of pulse laser systems for water depth determination as well as terrain profiling, the continuous wave laser holds significant potential for obtaining profiles of ocean waves. The Navy has spon-

sored a number of feasibility studies in this area including, more recently, one to acquire wind and wave information from altitudes up to 9,000 m.

Recent programs undertaken to prove the feasibility include those by NAVOCEANO (110) where the amplitude modulation of a continuous wave helium neon laser of red light (6238 Å) was utilized. Two instruments of similar design were tested, one from an aircraft and one from the Chesapeake Light Tower off Virginia Beach. The aircraft tests were conducted from an altitude of 150 m and provided very high resolution data ≈ .06 m.

Another experiment, this one funded by the Naval Air Systems Command utilized an Applied Research Laboratories (ARL) built system. This system also operates in a continuous wave configuration. Mounted in an aircraft flying at 60 meters above the surface and at 240 km/hr, the profilometer yielded data which are processed to produce a vertical section trace of the oceans surface showing ripples of 2.5 cm or less and waves of any height.

Additional experimentation which have already been conducted and are now being analyzed, include an airborne evaluation of Spectra Physics 25 mw system over Argus Island, Bermuda, the continental shelf waters, and the arctic.

4.5.5 Photography/Television for Sea State Determination

The use of airborne photography to determine sea state conditions is not a new technique. The direct measurement of waves or the use of scattered sunlight on the sea surface may be used. With the advent of satellites, a new dimension for observation has been added. The image of sunlight scattered at the sea surface is termed "sun glitter" or sun glint". Photographs have been made of it from aircraft as well as satellites and interpretation techniques have been developed. Aircraft studies have been made to determine the probability density of sea slopes and its relation to the wind field. The use of non-glitter portions in surface images obtained from meteorological satellite television data have also been studied for sea state estimates.

4.5.5.1 Direct Measurements

Apollo VI photographs of the surface of the ocean, acquired within two hours of noon, solar time, were found to show wave structure of the sea with

remarkable clarity (59). The wave length distribution was measured for about 1000 waves in a single photograph of about 25,000 sq. km area. At the time of photography there were no white caps on the sea. Breakers along islands and coasts were sharply visible in companion photographs. With better photographic definition wave height could probably also be measured from deformation of edges of cloud shadows.

4.5.5.2 Sun Glitter

The use of sun glitter to study the slope statistics of the sea was suggested and explored by Cox and Munk (25). They also suggested an empirical relation between the variance of the slopes and the surface wind velocity. Their basic idea is that if the sea surface were entirely calm, then an overhead observer would see a single, mirror-like reflection of the sun at the horizontal specular point. The sea, of course, is never mirror flat, but due to the short wavelength of light, can be considered as constructed from many small facets, each with its own inclination. The farther a facet is from the horizontal specular point, the greater is the inclination required to reflect light toward the observer. The location of the reflected light source can therefore be interpreted as a certain sea slope, and the average intensity of the light coming from this location can be interpreted as the frequency with which this particular slope occurs.

With the advent of satellite photography, the sun glitter has appeared as a major phenomenon on the photographs, and subsequently has been studied by a number of investigators (58, 144). Levanon (58) adapted the Cox-Munk technique to pictures taken with the spin scan cloud camera installed in ATS-1. The main modification involved the use of a sequence of photographs of a limited area (taken over a time period) rather than a single photograph of the whole sun glitter area. It was possible to by-pass the photographic and photometric processes and to do all the quantitative work on the received video signal.

These data were used to calculate the slope distribution, and from it the wind velocity, for three locations in April of 1967. The calculated values were compared to direct wind measurements obtained at these locations during the "Line Island Experiment". These comparisons revealed that the enormous height

of the observer did not significantly degrade the accuracy of the observation. When the wind direction is given, the accuracy of the calculated wind velocity, $\pm$ 1 m/sec., is as good as if the sun glitter was obtained from aircraft altitude.

Data analysis also showed the feasibility of studying the east-west component of the wave's slope distribution by using the sun as the radiation source with its movement, relative to the earth, as a scanning mechanism.

4.5.6 Conclusions

The significance of accurate and timely sea state information for the oceanographic user community dictates extensive research efforts in this area. Those techniques that have been receiving the most attention are radar scattering and microwave radiometry. From preliminary radar observations of the ocean surface, an increase in off-vertical radar backscatter with increasing "sea state" has been observed. It has been determined that wind speed is more important in determining radar return than is wave height, at least for most angles of incidence and for microwave lengths.

Although microwave radiometric observations of relatively calm seas and of controlled surfaces have been available for some time, measurements of microwave brightness temperature of the ocean under high sea state conditions have only recently been acquired. Data acquired at 1.55 cm and 3.2 cm indicate that sea surface emmission corresponds rather well to wave heights, at least up to 6 meters. However, it does not relate to windspeeds, especially for very strong winds. Other techniques such as laser profiling, direct seastate measurements (photography), and sun glitter measurements also show promise with a number of studies conducted.

Additional investigations are still required in all these R&D areas prior to establishing the feasibility of an operational sea state measuring system. In regards to the scatterometer and microwave studies extensive data at different frequencies needs to be acquired and correlated with a wide variety of surface conditions, i.e., wave heights, precipitation, clouds, winds, foam, etc. Limited tests are already underway or planned.

4.6 OCEAN CURRENTS

4.6.1 Introduction

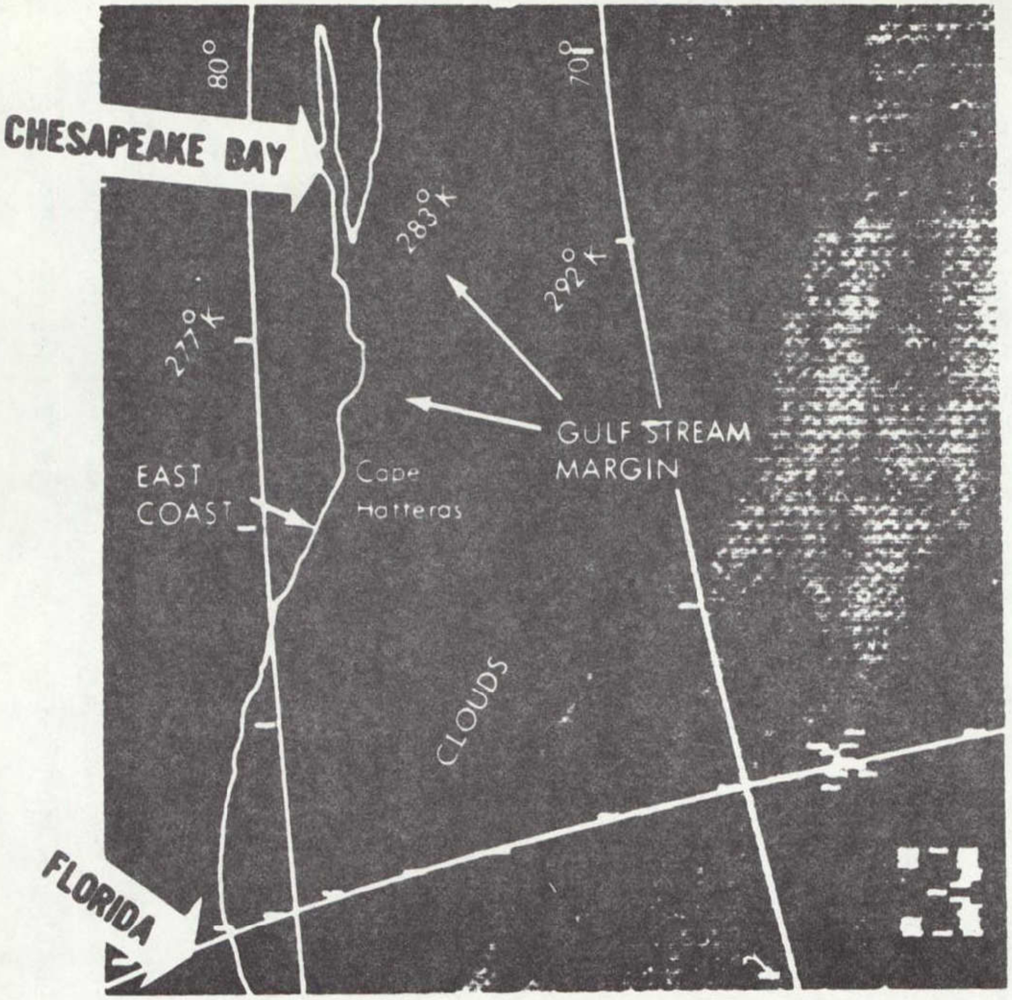
The principal parameter defining the boundary of an ocean surface current is the difference in temperature between the surrounding ocean water and the current. Temperature differences between these two mediums may vary between 2° and 10° C. This significant temperature difference can be detected remotely, from aircraft or spacecraft, using various remote sensors operating in the infrared region of the spectrum.

Because information on surface temperature is a prime factor for studying a number of other oceanic phenomena, in addition to currents, an overall discussion of temperature is presented separately in Section 4.4. This section is concerned with specific studies of ocean currents, and, for example, addresses the measruement of temperature only as it relates to ocean current measurement.

4.6.2 Identification of Ocean Currents from Satellite Infrared Data

Using available techniques, primarily designed for meteorological purposes, sea surface temperature discontinuities, such as those of the northwall of the Gulf Stream, have been located from spacecraft. Locations of the Gulf Stream northwall by means of daytime and nighttime Nimbus II HRIR data (145) agree to within 10 km. with those indicated by aircraft radiation data. This boundary or at least significant parts was seen in about 50 out of the 175 days for which data were analyzed. Figure 4.6-1 is an image and Figure 4.6-2 is a plot based on digital processing of Nimbus II HRIR data showing the Gulf Stream surface temperatures (145). Figure 4.6-3 shows the same data in an improved display - a computer grid - print map in a Mercator projection with the third dimension (temperature) transformed into a selected color scheme (145).

Similar results have also been obtained in analyses of the Agulhas Current boundary, the boundary between the Brazil and Falkland Currents, and the Kuroshio-Oyashio mixing region (145). These satellite radiation



00-SPOC-8

NIMBUS II HIGH RESOLUTION INFRARED IMAGERY CLEARLY DEPICTS THE GULF STREAM. TEMPERATURE VALUES WERE DETERMINED BY MICRO-DENSITOMETER.

NIMBUS IR IMAGERY CAN BE VERY USEFUL IN DETERMINING THE LOCATION, DISTRIBUTION, AND MOVEMENT OF THE MAJOR OCEAN WATER MASSES.

STUDIES OF THIS NATURE WILL BE OF GREAT VALUE TO OCEANOGRAPHERS, METEOROLOGISTS, AND TO THE WORLD'S FISHING AND SHIPPING INDUSTRIES.

NASA HQ SA67-15431
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Figure 4.5-1. HRIR Image of the Gulf Stream

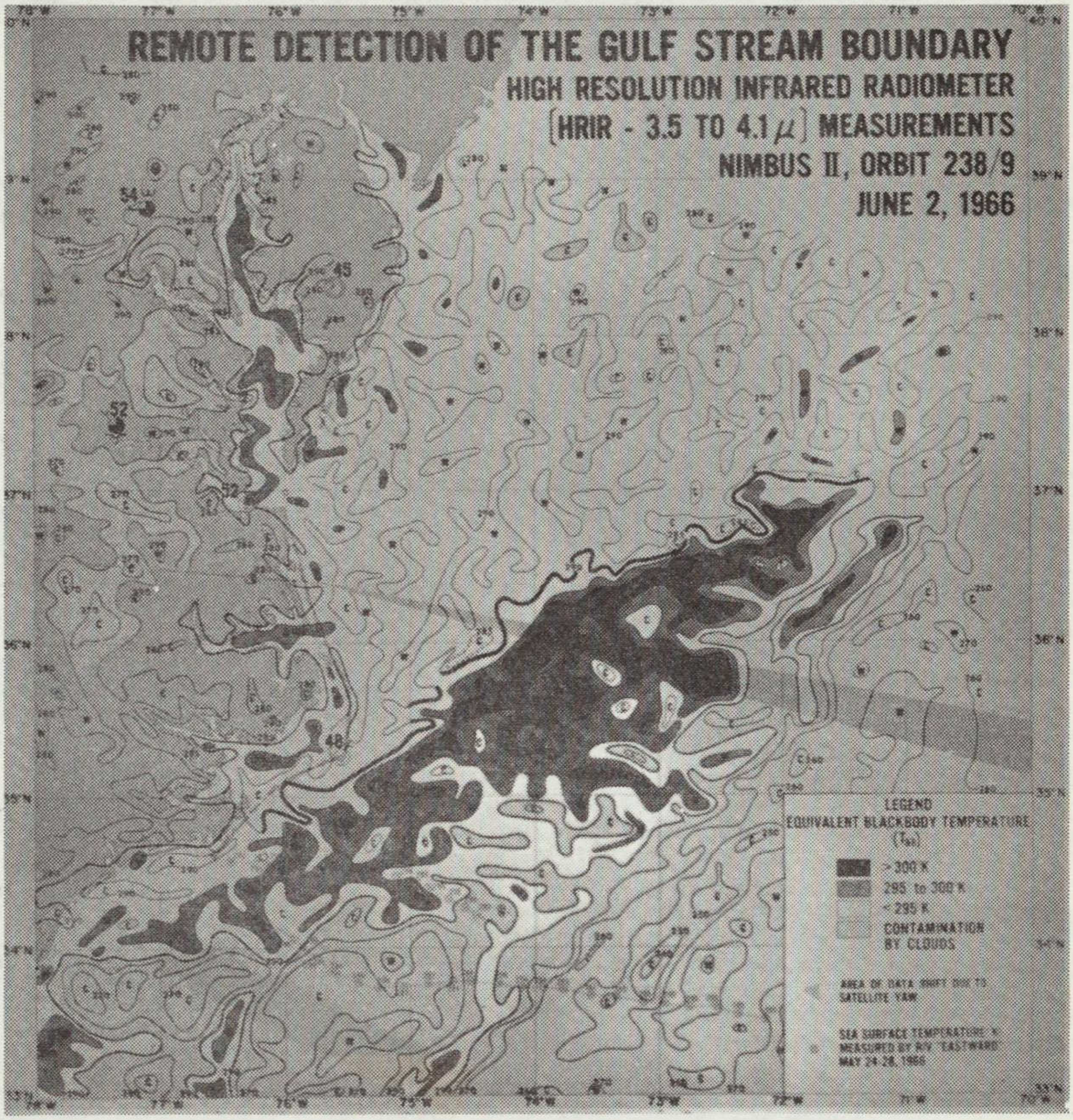


Figure 4.6-2. Nimbus 11 High Resolution Infrared Chart of the Gulf Stream Surfaces Temperatures on June 2, 1966. (Warnecke, Allison, Foshee, and Wilkerson, 1967).

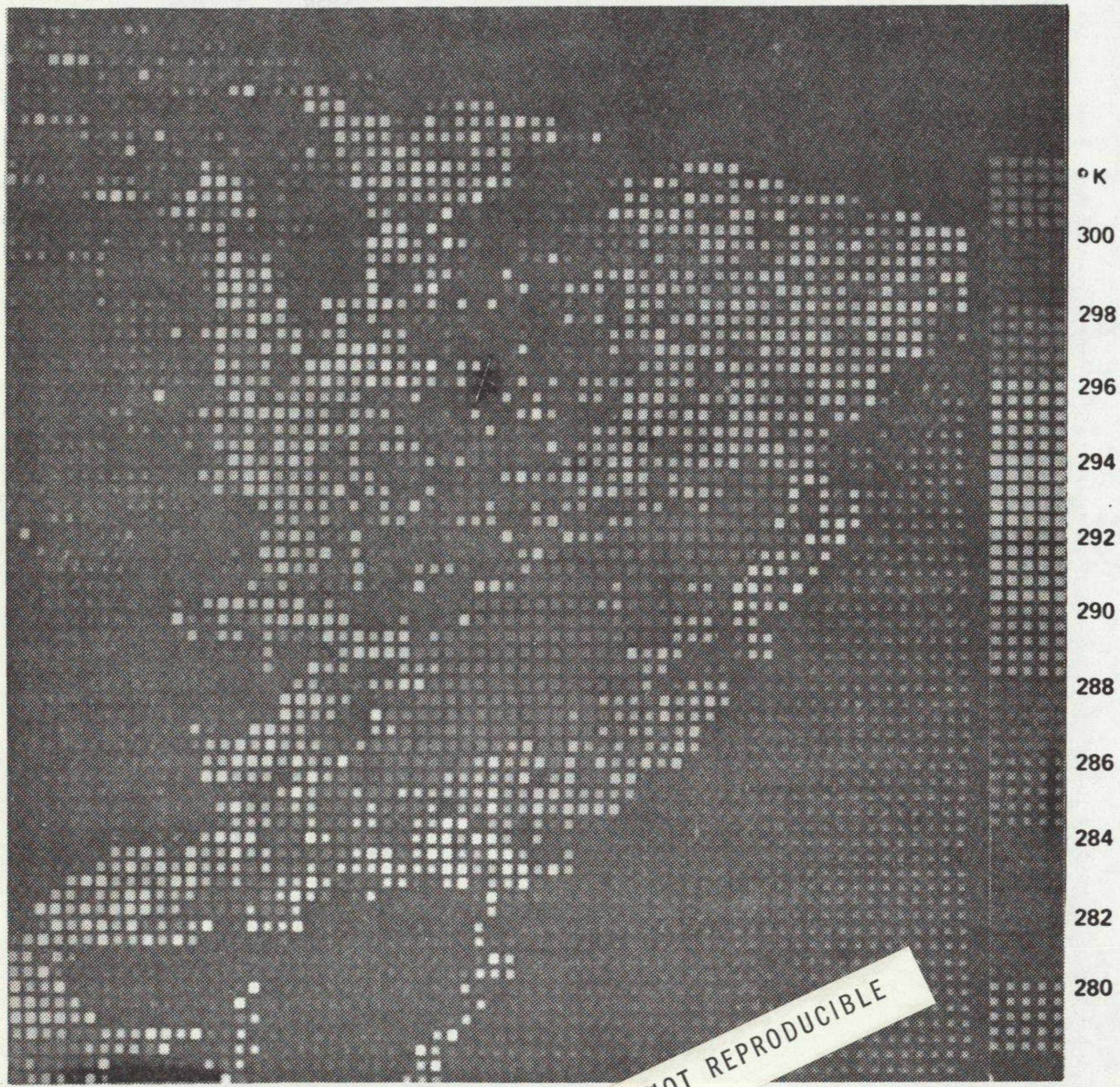


Figure 4.6-3. Digital color print of computer grid print map of Nimbus II HRIR measurements from orbit 238 on June 2, 1966 over the Gulf Stream (oscillatory noise eliminated by numerical filter). Blue and grey areas indicate clouds and/or land. The North Wall of the Gulf Stream stands out under clear skies; its southern boundary is obscured by clouds. Note the higher temperatures shown in Chesapeake Bay and the Delaware River if compared with the near-shore ocean temperatures.

observations suggest that the Brazil-Falkland Current boundary, which is associated with a surface temperature discontinuity, is as sharp and strong as the Gulf Stream northwall. The Agulhas Current exhibits a similar temperature discontinuity along its western boundary, which separates it from the Benguela Current surface waters (145).

4.6.3 Determination of Ocean Currents from Photographic Observations

Present photographic (television) techniques of observations from satellites designed for meteorological purposes do not have the spatial or spectral resolution necessary to determine boundaries of ocean currents directly. Thus, at present one can only obtain inferences under certain conditions of the location of currents. This indirect detection of ocean currents is possible because of the effect of the sea surface temperature changes associated with currents on televised cloud features. Over the ocean, with its comparatively small horizontal temperature differences, the surface effect on cloud patterns is usually overridden by the effect of internal atmospheric processes. However, in the case of rather homogeneous horizontal conditions and fairly weak large-scale dynamic activity in the atmosphere, sea surface temperature changes associated with currents can be reflected in the cloud patterns as is shown in Figure 4. 6-4, an ATS II TV photograph of the eastern tropical Pacific Ocean (145). In this picture a clear zone seemingly follows the expected course of the Humbolt Current which is a pronounced cold water current that flows westward from the South American coast at the latitude of Punta Negra, Peru. The current is, on the average, 2° to 5° C colder than the surrounding sea regions. This temperature difference seems to be quite sufficient to suppress the formation of convection cloudiness which covers all the surrounding warm water areas.

In the series of photographs provided by the ATS III satellite, which was stationary over the equator near South America, the outlines of the Humbolt Current are also a pronounced phenomenon in almost every picture (145).

Figure 4.6-4. ATS-11 photograph taken on April 10, 1967, 1855 GMT, over the eastern Pacific Ocean. South America in the lower right is outlined by heavy cloudiness. The Peruvian coast is under clear skies; the Humboldt Current is marked by the extended band of no or little cloudiness through the center of the picture. Central America, the Gulf Coast, and southern Baja California are visible in the upper center portions.

From the foregoing discussion, it can be concluded that in some cases present satellite photography can provide information useful in detecting ocean currents exhibiting pronounced sea surface temperature discontinuities. The location must be inferred visually from characteristic modifications of existing cloud patterns induced by local temperature related vertical circulations in the lower atmosphere. However, since the cloud features merely reflect induced local lower tropospheric circulations rather than the sea surface temperature itself, the locations of the ocean current boundary and the cloud boundary need not coincide because of horizontal air motion across the current boundary. Therefore, a displacement of approximately 10 kilometers toward the warmer water often occurs. Also, a large-scale atmospheric flow pattern may be superimposed on the local circulation, thus resulting in an additional displacement of the cloud boundary in a direction dependent on the superimposed wind field.

These effects will complicate the accurate location of an ocean current boundary through cloud photography due to their influence on cloud patterns. No detailed and quantitative investigation of this problem has been accomplished.

4.6.4 Aircraft and Spacecraft Feasibility Studies

Remote sensor data have been acquired from aircraft over selected ocean current boundaries, such as the Gulf Stream, to determine the feasibility of the techniques. For example, in one experiment (74), IR systems and photographic systems were utilized to detect the northern wall of the Gulf Stream. Figure 4.6-5 is an IR image showing the contrast between the colder shelf water (light) and the warmer Gulf Stream (dark). Figure 4.6-6 depicts the visual differences apparent along the meandering boundary and the sargassum which accumulates along the edge.

The Naval Oceanographic Office has devised a technique (97) for locating and tracking the Gulf Stream using an infrared radiation thermometer. The radiometer had a one-second time constant, an operational accuracy of ± 0.4°C 95% of the time, and is normally flown at a 300 m altitude. The Gulf Stream was detected by the strong temperature gradient that occurs along

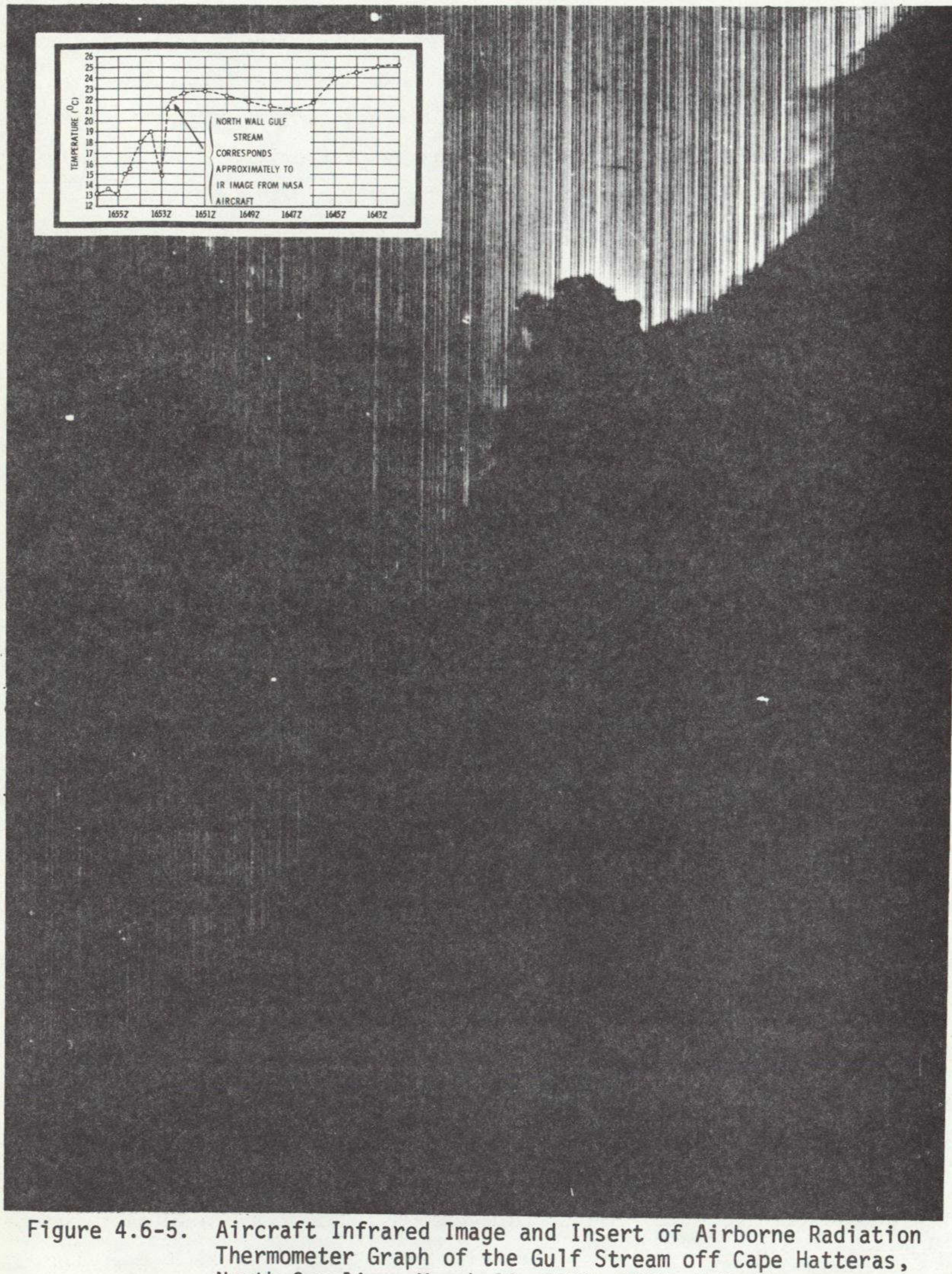


Figure 4.6-5. Aircraft Infrared Image and Insert of Airborne Radiation Thermometer Graph of the Gulf Stream off Cape Hatteras, North Carolina; March 12, 1966, NASA; U.S. Navy.

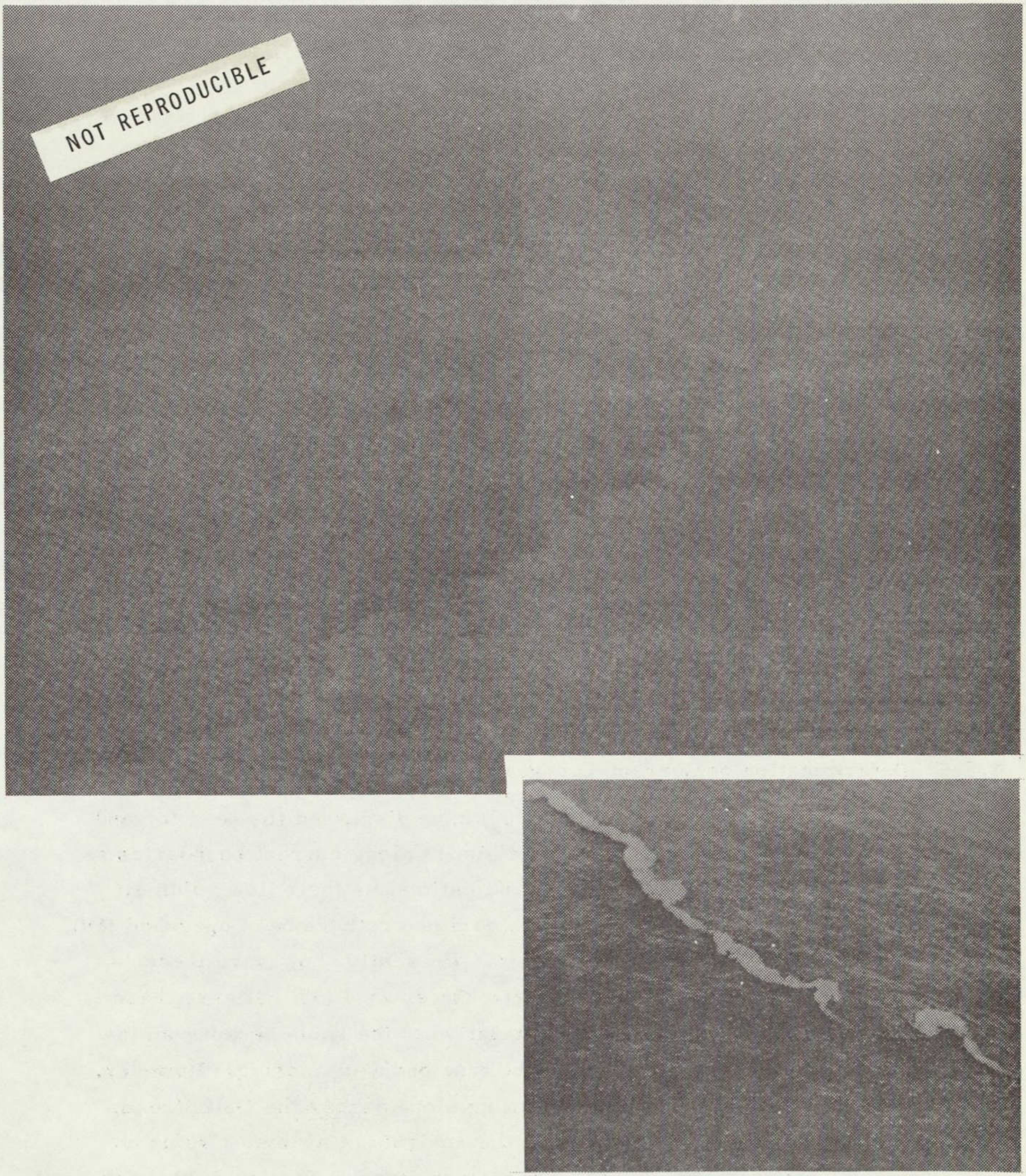


Figure 4.6-6. Color Variations at the Edge of the Gulf Stream (35°N, 74° 30'W) Aircraft Photo; March 12, 1966, U.S. Navy

the northern boundary. In the vicinity of the gradient, the IR thermometer data is used to navigate the aircraft. Positions of the northern edge of the Gulf Stream between 65° and 75° W showed that meanders exist, average 520 km. in length, and move from west to east at a speed of about 15 cm/sec in a mean direction of 068°.

Analysis of selected Gemini photographs has shown that for photographic systems to provide useful data they must be extremely sensitive to small variations of available light, primarily in the blue green spectrum. In addition, efforts should be made to enhance the contrast effects during data collection and processing. Color film is most advantageous since small variations of color contrast are more easily detectable by the normal human eye than are small changes in shades of gray. For example, Figure 4.6-7 a Gemini photograph, clearly delineates coastal currents. The judicious choice of spectrum, film, processing, etc., is mandatory since in the open ocean most of the light reflected from below the surface is blue to green, and the differences in water composition are considerably smaller than along the coast lines. Also, variable sun angle over an ocean basin will result in varying amounts of light backscattered from the sea. Radiation losses due to the atmosphere will further reduce photo contrast.

4.6.5 Determination of Current Topography

Several investigators (35, 39, 66, 69) have discussed the need for and the possibility of determining sea surface slopes along current boundaries as a means of identifying surface currents and estimating their flow volume. Vertical resolutions on the order of a few decimeters have been specified (69), which may be achievable in the near future. Presently, however, these resolutions are beyond the state of the art. Greenwood (39) believes there is little hope of getting sea surface slopes relative to the geoid because an independent equally accurate estimate of the true geoid is missing. However, small-scale features such as the very strong slope across the Gulf Stream might be detectable as an irregularity in the analysis of altimeter returns. Additional information on these concepts may be found in Section 4.12 - Sea Surface Topography.

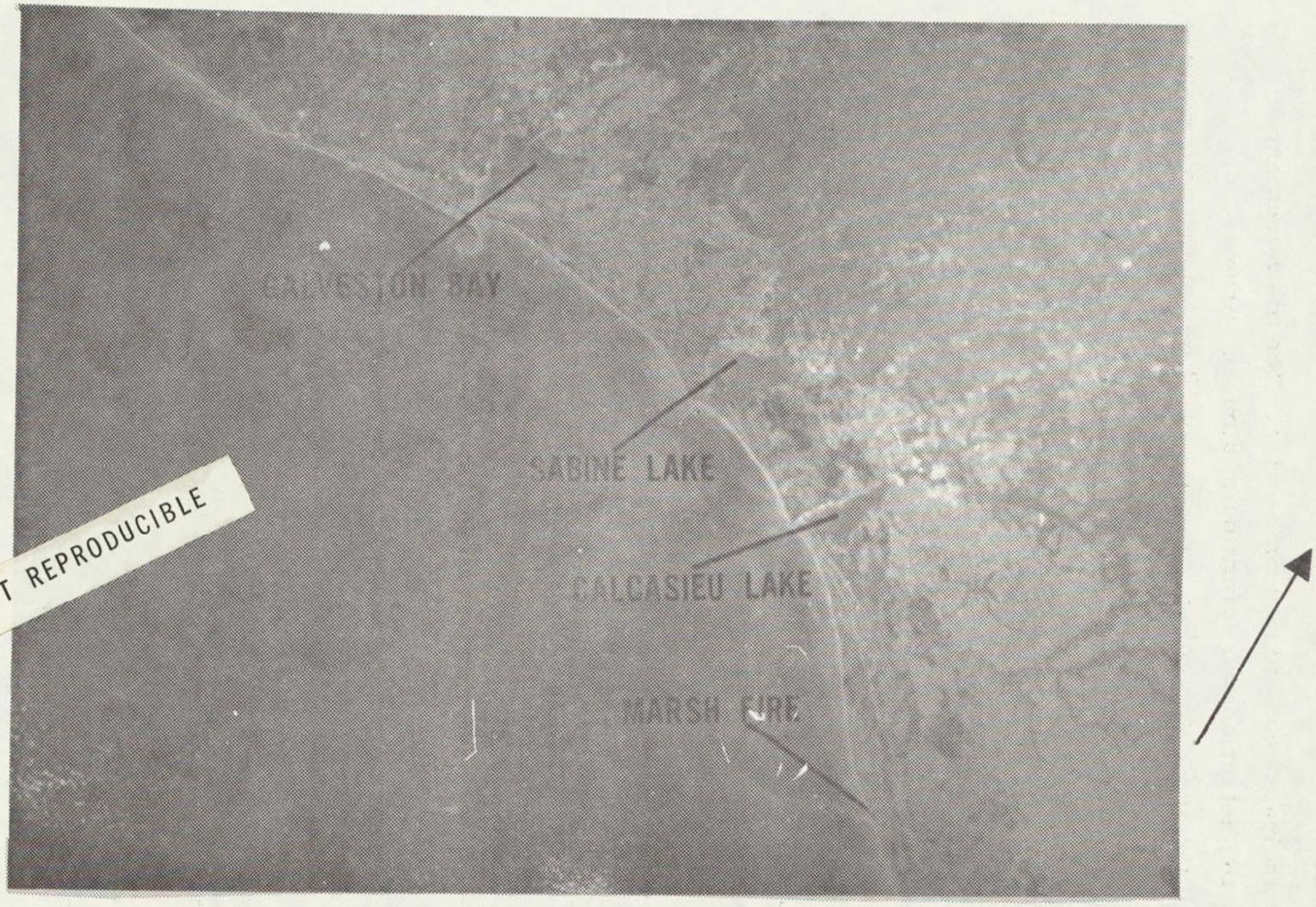


Figure 4.6-7 Coastal currents are flowing toward the southwest in response to wind blowing at 25 km hr from N.E. Sediment laden water is seen to be flowing out through Sabine Pass and the Jetties of Galveston Bay. An interference eddy can be noted west of the Galveston Jetty. Note seaward drift of smoke from marsh fire.

4.6.6 Conclusions

The two principal ocean surface parameters, the measurement of which will allow the detection and definition of surface currents, are surface temperature and water color. The use of IR techniques to measure the temperature differences between the current and the surrounding water has received the most attention and consequently shows the greatest promise in the near future. This is especially true for those currents exhibiting substantial temperature differences from the surrounding medium, i.e., the Gulf Stream.

The primary deficiency of sensing in the IR spectrum is the overall attentuation of the signal by the atmosphere and, in particular, the clouds. However, since currents are not thought to change as rapidly and as radically as some other oceanic phenomena, IR systems may be perfectly satisfactory. For detailed oceanographic research work in the future, a higher spatial resolution than available with the HRIR and a shift to the 10.5 to 12.5μ region is desirable. Simultaneous window channel observations with a visible channel (0.55 to 0.75μ) would be necessary to delineate and eliminate cloud contaminated areas within the field of view of the radiometer.

The use of passive microwave techniques for measuring sea surface temperature and consequently surface currents appears to have one distinct advantage, all weather capabilities. However, extensive R&D is still required before the system can be made operational for this purpose from spacecraft.

The measurement of a third parameter, sea surface topography, also holds potential for surface current detection and has received some limited theoretical study for remote sensing application. The theory is that many currents have sharply defined relief on their boundaries that could be detected with a very accurate altimeter ($\pm$10 cm). Due to the high accuracy requirements and the present state of the art in space altimetry, it is believed that this technique will not be available in the near future, (see Section 4.12).

4.7 SEA ICE

4.7.1 Introduction

Early experiments involving interpretation and use of satellite imagery have already demonstrated the feasibility of using space vehicles to complement and supplement the conventional ice reconnaissance and surveillance programs (19). Other techniques that have been tested from aircraft and also show particular promise, especially in view of the fact that they are theoretically "all weather," are radar imagery, radar scatterometry, and microwave radiometry.

4.7.2 Operational Aircraft Programs

Today the primary vehicle for obtaining ice information is the aircraft. The Naval Oceanographic Office and the Lake Survey as well as the Coast Guard actively acquire ice data from aircraft. Since 1953, NAVOCEANO has had a regular program of ice reconnaissance and ice forecasting to support surface shipping. In 1962 they initiated a major ice surveillance program for the collection and compilation of statistical data concerning the distribution of various ice features and conditions in the arctic. The program, termed Project Birds Eye, consists of ten missions a year, each mission comprising several flights, which cover a large portion of the Arctic Ocean and its marginal seas. This program has been strongly restricted by reliance on visual observation with its inherent human limitation for quantitatively estimating magnitudes of ice canopy features.

Aerial ice reconnaissance aircraft are primarily used to search for leads or openings in the ice that are large enough for ships to get through. In addition, the aerial ice observer looks for certain features which indicate ice formation, advance, or breakup, or characteristics which show that icebreakers could be used to open ice covered ports or waterways for shipping. Many aircraft are employed for ice reconnaissance missions, both over the oceans and in the Great Lakes region. Ship and land station reports complement the aerial reconnaissance program. Information from these sources is sent to major ice centrals or other collection centers for use in forecasting.

For long-range ice prediction (30 days or more) the forecaster is primarily interested in the location of sea ice boundaries (± 16 km), concentration (percentage of ice cover within a given boundary), and depth (in cm's). For short-range forecasts of five days or less, and for close support of ship operations, additional information is needed: ice type (ranging from slush to large ice fields), age (new or young, medium, or winter), topography (presence of ridges or hummocks several cm's or meters in height), presence of cracks or other small open water leads, and other features. When studying ice conditions in bays or off-shore sites prior to establishing petroleum drilling rigs much of this same information is required. Aircraft are also used to follow the movement of large ice features (several kilometers across) as indicators of ocean currents, and for iceberg patrol.

Weather, logistics, and economics dictate the success of many aerial reconnaissance missions. Furthermore, since aerial ice reconnaissance is largely subjective, the accuracy of the observations will be largely contingent upon the training and experience of the observer. The observer is also limited in the size of the area which he can view effectively, usually a distance of about 25 km on either side of the aircraft. An added problem is the possibility of location error due to navigation difficulties, particularly in arctic and antarctic regions.

4.7.3 Significant Experimental Results Using Space Acquired Data

Project TIREC, a joint U.S.-Canadian program (19) to coordinate aerial and surface ice observations with TIROS IV ice photography, led to the development of satellite ice reconnaissance techniques which are now being applied operationally. In this operational application satellite imagery is used to "tie in" point observations from shore stations and obtain a complete picture of the shore-line extent of ice. Locally, this information can be used to predict ice breakup or formation along coastal areas where small commercial or recreational activities, such as fishing, are of interest. Leads, polynyas, and other open water features 800 m or larger can also be detected in satellite imagery.

On a larger scale, satellite photographs of the Great Lakes region have been used as an aid in preparing forecasts of ice breakup for commercial

shipping activities. Experience (19) has shown that, over areas of major economic interest, satellite photography suitable for ice reconnaissance purposes should be obtained once or more a week, depending on the application. This frequency is enough to give a good indication of the ice extent and stage of formation or breakup.

Satellite ice observations can also play a role in detecting and tracing ocean currents. During Project TIREC, an ice area off the east Newfoundland coast was photographed simultaneously by aircraft and by satellite (19). Swirling eddy patterns were seen which were produced by the confluence of the Labrador Current and the northeastward extension of the Gulf Stream. The patterns are visible because of the presence of ice. Other similar patterns have been observed in satellite and aircraft imagery of other areas.

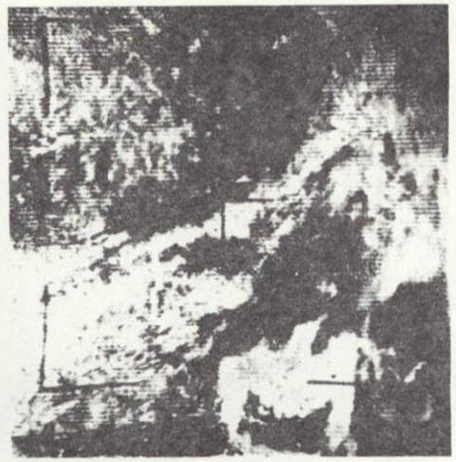
Another example of sea ice movement due to current effects is shown in Figure 4.7-1. The ice is observed to drift eastward and northward from the southern and western Gulf of St. Lawrence, then out of the Gulf through Cabot Strait and southward along the east coast of Cape Breton. This series of pictures is illustrative of the many which have been obtained and examined in connection with sea ice studies (19). More recently, the rotation and movement of large ice floes caught in the East Greenland Current were followed for several days using Nimbus II photographs.

Using Nimbus I HRIR data, it has been reported (102, 149) that considerable detail was delineated in the antarctic pack ice. M. Predoehl (103) in a study to establish boundaries of the antarctic pack ice from both TV photographs (AVCS) and HRIR data, found that in the HRIR pictures the pack ice edge was not as clearly delineated as in the AVCS photographs. It appeared as a gradual change in brightness corresponding to the change from the warmer water to the colder ice. However, abrupt changes were also readily noticeable in the HRIR, such as at the edge of the Antarctic Continent where a large temperature difference exists.

A study by Allied Research (9), sponsored by SPOC, was undertaken to evaluate the use of nighttime HRIR imagery from Nimbus I and II satellites for mapping distributions of arctic sea ice. In all HRIR film strips analyzed, areas

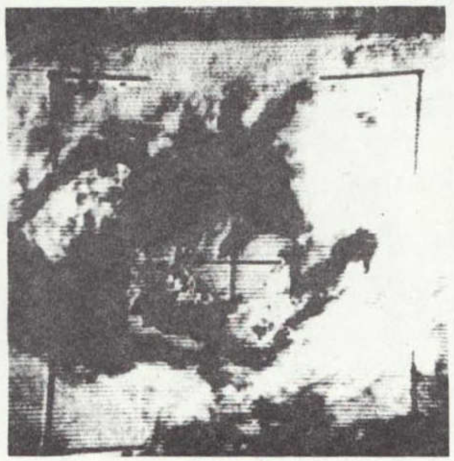
ORBIT 779, APRIL 3, 1962

ORBIT 793, APRIL 4, 1962



ORBIT 808, APRIL 5, 1962

ORBIT 822, APRIL 6, 1962



ORBIT 835, APRIL 7, 1962

ORBIT 908, APRIL 12, 1962

Figure 4.7-1 A series of TIROS IV satellite photographs taken during Project TIREC, illustrating how the movement of sea ice features can be followed using satellite imagery. The ice is observed to move in an easterly and northeasterly direction, out of the Gulf of St. Lawrence, through Cabot Strait, then southward along the east coast of Cape Breton. More recently, the movement of large ice floes along the east Greenland coast has been followed in Nimbus II satellite pictures.

of permanent polar ice appeared much colder than areas of ice-free water. Similarly, thicker ice observed later in the fall (November) is more easily detectable than newly formed or broken ice because of the greater temperature contrast with the open water. Conversely, distinction between land and ice-covered water becomes more difficult as the season advances and the land surface becomes colder.

Three additional factors have a significant effect on the interpretation of HRIR data in terms of sea ice. One factor is data noise, which can be of sufficient magnitude to interfere with the detection of small temperature variations. Secondly, the gray-scale resolution of the data in the film-strip format does not permit small temperature differences to be detected. In the temperature range near $273^{\circ}K$, differences of only a few degrees can be significant for distinguishing between ice and water. Thirdly, low stratus or fog can be mistakenly identified as newly formed ice, since both may have a similar appearance in the HRIR imagery.

Allied Research (9) concluded that nighttime HRIR imagery is an effective means of mapping sea ice distribution, particularly the large scale features. When the temperature contrast is sufficient, such as between an unfrozen inlet and the surrounding land or between an open lead and thick pack ice, features of less than 8 km width can be detected.

Problems encountered were related primarily to cloud interference and low spatial resolution. The cloud problems were especially acute when the surface was very cold thus making the distinction between cloud and other geophysical features more difficult. More reliable distinction between ice and low cloud, and more reliable mapping of partial ice cover, would be achieved with improved spatial resolution of the HRIR sensor. Even without a significant improvement in spatial resolution, however, improved mapping reliability may be possible through the application of techniques to enhance the gray-scale resolution of the HRIR film strips.

4.7.4 Significant Experimental Results Using Aircraft Acquired Data

Several remote sensing techniques have the basic ability to acquire ice data. However, since frequent all-weather information is required, and the

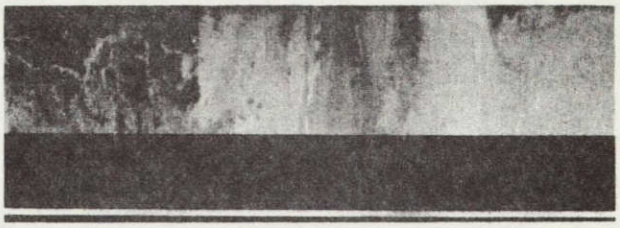
regions of ice occurrence are often cloud-obscured, and it is sometimes difficult to distinguish between cloud and ice in the visible spectrum, it appears that passive and active microwave techniques would be most advantageous. Results from studies using remote sensors flown on aircraft to determine sea ice type and extent have been encouraging.

4.7.4.1 Multispectral Surveys of Sea Ice

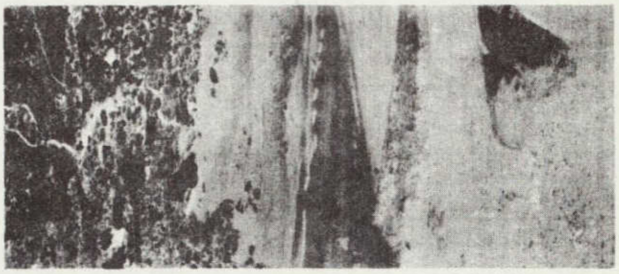
A survey of the Arctic region sea ice in the vicinity of Point Barrow, Alaska, was conducted by the University of Michigan (46) in October 1967 using a multispectral scanning system. This system developed at Michigan is capable of obtaining and recording on magnetic tape simultaneous imagery in eighteen discrete spectral brands ranging from 0.32 to 13.5 microns. The primary element of the system is a 12 channel spectrometer, operating between 0.4 and 1.0 micron. In addition to the spectrometer, five other detectors operating between 0.32 and 13.5 microns provide data in six discrete bands.

Figure 4.7-2 is an example of the imagery obtained and shows sea ice thermal patterns in the Arctic Ocean off Elson Lagoon. Both calibrated (using reference lamps and blackbody plates) and uncalibrated data are shown. The light strip at the bottom of the calibrated imagery represents the hot calibration plate ($0^{o}C$) while the dark area around this strip represents the cold calibration plate ($-15^{o}C$). In the imagery itself, the cold (dark) inhomogeneous stippled areas are small polar floes and cakes from previous years refrozen into a matrix of new winter ice ~ 30 cm thick with light snow cover. The warmer (medium gray) areas are young sea ice 10 to 15 cm thick. The warmest areas are refrozen leads (cracks) and polynyas (holes) covered with ice rind about 5 cm or less in thickness. The effect of wind upon the ice formation can be seen by the vertical banding of the ice types in the center portion of the imagery, perpendicular to the prevailing wind direction.

Figure 4.7-3 shows young sea ice formation near the shoreline at Barrow, Alaska. Note that in order to show the subtle thermal patterns in the thin ice, the very cold land area (right side of image) was forced outside the dynamic range of the film. The temperature of the land is about $-15^{o}C$ while the temperature of the warmest ice is about $-2^{o}C$. The large geometric patterns on



Calibrated 37° FOV



Uncalibrated 80° FOV

Figure 4.7-2 8-13.5 MICRON THERMAL IMAGERY OF SEA ICE. Data acquired east of Elson Lagoon at 1700 hours on October 11, 1967 at an altitude of 2,000 feet. Scale: 1 inch = 1,000 feet. (46)

Figure 4.7-3 8-13.5 MICRON THERMAL IMAGERY OF YOUNG SEA ICE. Data acquired northwest of Barrow Village at 1200 hours on October 16, 1967, at an altitude of 6,000 feet. Scale: 1 inch = 3,000 feet. (46)

the left side of the image are produced by heavily rafted young ice 5 to 15 cm thick, with the coldest areas representing the thickest portions. The generally warmer ice nearer shore is composed of semi-solid pancake ice and solid ice rind less than 5 cm thick. The linear striations in this area which generally parallel the shore line are due to sea smoke (thin fog) which has become oriented by the wind. The presence of the sea smoke is indicative of the nonsolid nature of the pancake ice and the presence of some free water surface.

4.7.4.2 Laser Studies of Sea Ice

Recent aircraft tests of a laser terrain profiling system over the Beaufort Sea (88) demonstrated the feasibility of the laser for accurately profiling the sea ice surface and measuring pressure ridge heights. A reflectometer coupled with the laser system provided useful complementary data by depicting surface reflectivity of the sunlight and the transmitted laser light. The system employed a Spectra-Physics Geodolite 3A which uses a modulated CW laser technique to obtain continuous measurement of instrument height above the surface. The illuminated spot on the surface from a height of 300 m is only 3 cm in diameter. Figure 4.7-4 shows combined records from a 300-meter altitude of terrain profile and surface reflectivity along with a photograph of the ice surface traversed.

The laser profile reveals directly the surface topography, or roughness of the ice surface and consequently identification of categorical ice ages can usually be made through interpretation of the character of the profile. This information can often be coupled with information about the surface reflectivity to aid in interpretations.

The unique capability of the laser system, however, is that of measuring feature height and the ability for continuous profiling of surfaces with respect to a relatively constant reference level. Further refinement of instrumentation used to sense vertical fluctuations of the aircraft with respect to this constant reference level may enable the use of the laser system for estimating sea ice thickness, based on precisely measured profiles of the ice surface above a sea level reference. This estimate would be based on a known ratio of sea ice height above water to sea ice depth below water. At present, an airborne

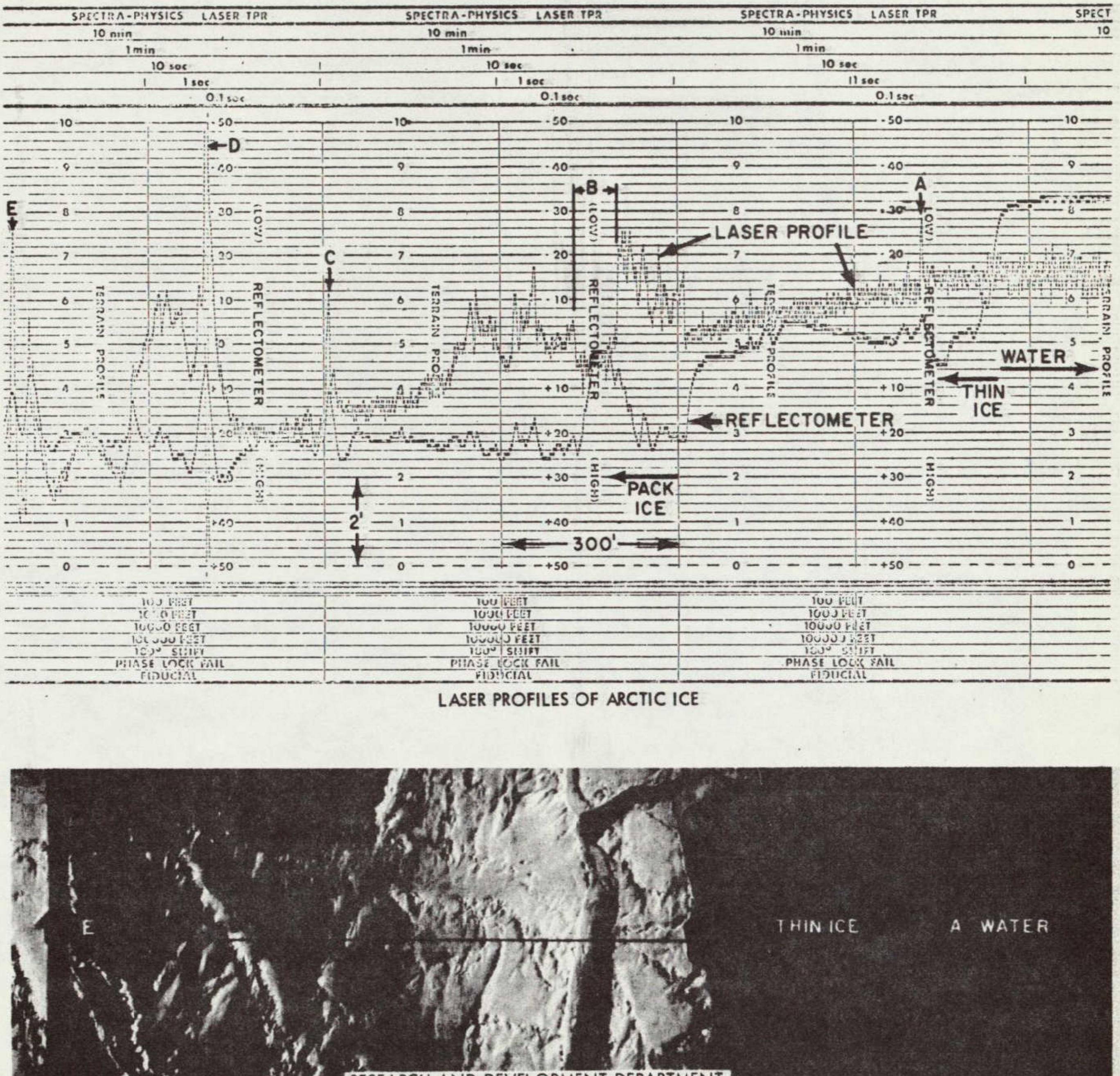


Figure 4.7-4 Comparison of terrain profile and terrain reflectivity records with aerial photograph showing the ice terrain traversed by the laser profiler and reflectometer indicates the unique value of this system for sea ice reconnaissance.(88)

system could support statistical ice data collection programs by providing objective supplementary data concerning distributions in frequency and sizes of important ice features. This system, like the infrared system, is restricted or limited by atmospheric obscurants. Further testing under varying atmospheric conditions and during summer ice conditions is anticipated.

4.7.4.3 Infrared Studies of Sea Ice

In 1964, the Naval Oceanographic Office began experiments to test and evaluate airborne infrared scanners to determine their applicability to sea ice reconnaissance. Infrared scanners were flown during both day and nighttime periods over the arctic sea ice. These experiments demonstrated that many sea ice parameters could be detected using infrared imaging techniques (88). The ice surface thermal pattern during the daytime is strongly influenced by solar heating and by heat conducted through the ice from the water, whereas during nighttime, heat conducted through the ice from the water is the single most dominant and persistent influence controlling the surface thermal pattern. Additionally, weather conditions such as air temperature, cloud cover, and wind may have a very strong and extremely variable influence on the surface thermal pattern.

When comparing a conventional aerial photograph with an infrared image, it is readily apparent that the thermal image provides a much stronger capability for detection and identification of ice fracture patterns and early stages of ice development (88). The thermal image not only permits easier detection of fracture zones in the polar pack, but also enables the interpreter to more readily group fractures of the same deformation period and to chronologically date deformation periods. This is often impossible with conventional photography. Moreover infrared systems can be used successfully during nighttime. The primary disadvantage of the infrared system is that atmospheric obscurants restrict its all-weather use.

Ice-water boundaries present high contrast in the passive infrared ($3-15\mu$) spectral region. Furthermore, variations in ice thickness are revealed in infrared images by differences in surface temperature, even through snow cover. Relative thickness of adjacent ice areas can thus be estimated by this

means (77). However, since the surface temperature is determined by numerous other parameters, such as air temperature, percentage of cloud cover, wind velocity, humidity, sun elevation, previous weather history, thickness and compactness of snow cover, and ice conductivity, IR techniques do not appear to be promising for the determination of the absolute value of ice thickness or even the relative thickness of widely separated ice areas.

4.7.4.4 Radar Imagery Studies of Sea Ice

The capability of radar to provide useful sea ice reconnaissance and forecasting information under weather and lighting conditions unsuitable for visual sensing has attracted considerable interest. Radar, in the form of a side-looking imaging system, was used experimentally for mapping of the arctic ice as early as 1957. The majority of this work was sponsored by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), using the AN/APQ-56 airborne radar system flown by the U.S. Air Force. Additional data have been acquired by NASA/USCG using a modified AN/DPD-2 radar imager (164). These imaging systems record marked differences between the radar return amplitudes from various ice types.

Airborne side-looking radar systems normally provide image maps which display good surface feature resolution, have wide dynamic range, and cover a relatively broad surface area compared to other airborne remote sensors. These factors, coupled with the radar capability for successful operation during almost any weather situation, day or night, place side-looking radar high among potential ice reconnaissance sensors.

Figure 4.7-5 shows a section of a side-looking radar (K-band) image taken several years ago over the arctic ice pack north of Greenland. The imagery was obtained during experiments conducted by CRREL (88). The black or dark gray features in the imagery represent areas of recent fracturing and divergence of the ice canopy. These areas consist of open water and thin ice. Broad aerial coverage of this nature enables determination of the general orientation of fracture patterns and gives evidence as to scale of the deformational fracture pattern. Sequential coverage of the same area would enable studies of ice motion along with evidence of the resultant ice deformation.

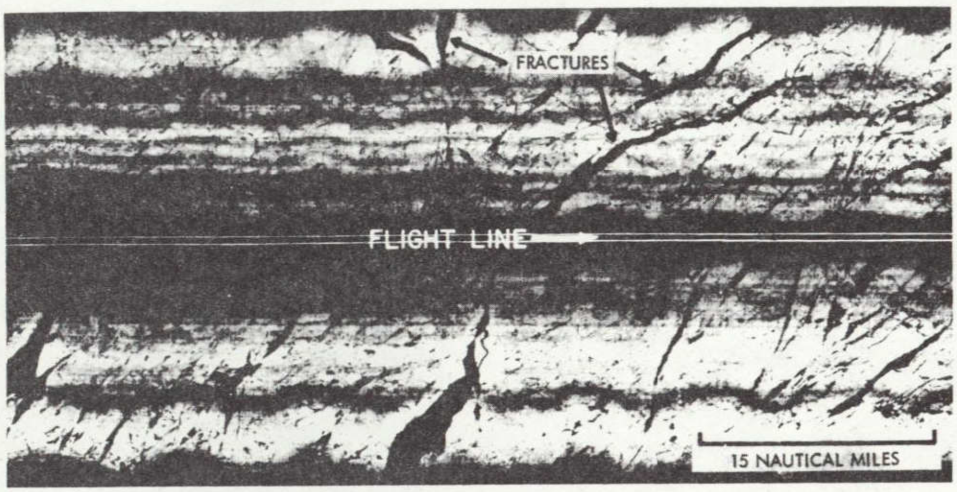


Figure 4.7-5 The potential value of airborne side-looking radar in sea ice reconnaissance lies in the ability to obtain, in a short time, broad-area maps portraying discrete feature detail and large-scale patterns where weather or darkness may preclude the use of the other sensors. (88)

4.7.4.5 Radar Scatterometry Studies of Sea Ice

A scatterometer is a radar system used to record the differential scattering coefficient of terrain as a function of incidence angle. A 2.25 cm scatterometer (a Ryan Redop system mounted in NASA's P3A) has been used in a number of sea ice experiments. The instrument transmits a vertically-polarized CW signal and collects return from an illuminated region ± 60° along the flight line and 3° wide. The return is processed through doppler filters to obtain the scattering coefficient at each of several discrete angles within the beam. The data are then presented in such a way that, regardless of the angle at which the data are recorded, the return is from a particular "cell" on the terrain. That is, a final plot of scattering coefficient versus incidence angle is produced that represents the "signature" of one particular area along the flight line. A "cell" is approximately square and its area is a function of the altitude of the system above the terrain. From an altitude of 300 m, a "cell" is approximately 30 m on a side.

An experiment using this instrument to determine characteristics of radar backscatter from various types of ice was conducted in 1967 with J. Rouse as principal investigator (116). This study was restricted by being limited to a single frequency and polarization. Hopefully, better understandings of the effects of these two parameters will be forthcoming from the Naval Research Laboratory four-frequency, multipolarization radar system discussed below, and from future radar scatterometry flights being scheduled by NASA.

During April 1968, the Naval Oceanographic Office conducted a multi-frequency (8910 MHz, 4455 MHz, 1225 MHz, and 438 MHz) multipolarization radar experiment over the Arctic Ocean sea ice using the Naval Research Laboratory synthetic aperture side-looking radar (40). Imagery obtained at X-band on horizontal and vertical polarization exhibit varying shades of gray which appear to be associated with the differing roughness of the ice. From a knowledge of the ice roughness, ice analysts are able to infer the age and thus the melting rate of ice patches. The L-band frequency appears to respond more strongly to the boundaries of the ice patches than to the roughness of the ice. Possible reasons are that the roughness of the various ice types viewed is smaller than required to reflect the L-band well or that penetration of the

ice tended to smooth the air/ice interface. Apparent penetration of the ice by radar transmissions was also observed in the imagery.

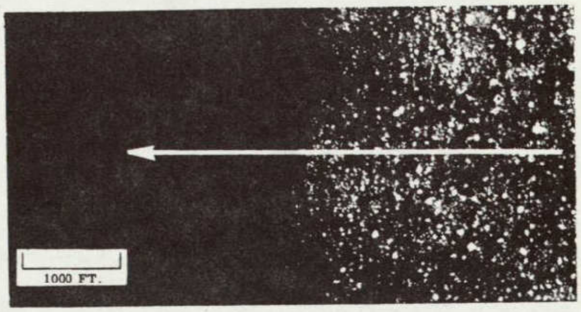
Visual comparison of the results gave some insight into the behavior of the return. However, such approaches are qualitative, so a "roughness factor" was found for each ice type by fitting the scattering coefficient data into a theory based on the Kirchhoff-Huygens principle (116). The identification of ice types obtained by determining their surface roughness factor is based solely on topography. Several ice types are differentially based on the scattering-coefficient angular dependence compared with the returns from various other ice types and with theoretical predictions.

During the mission extensive cloud cover was encountered degrading much of the photography; however, the radar data were of excellent quality.

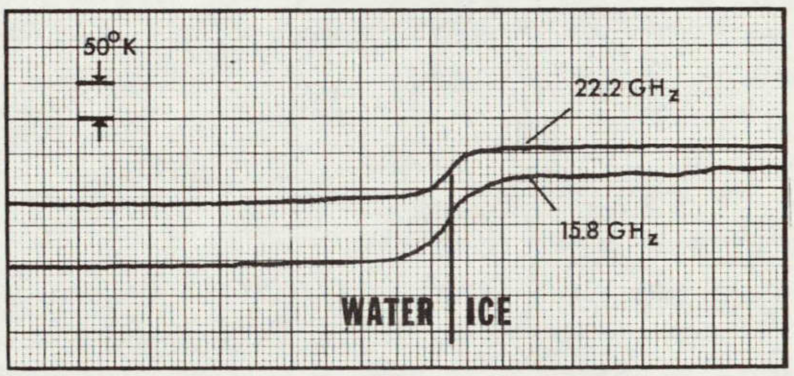
4.7.4.6 Microwave Studies of Sea Ice

A number of aircraft missions have been flown over sea ice to determine detectability using passive microwave techniques. Sensing in the microwave region (0.03-30 cm) has an advantage for many applications and especially for arctic areas, because the radiation is relatively insensitive to atmospheric scattering and attenuation. Microwave sensing also provides some distinctive signatures not obtainable in the visible or infrared spectrum. Microwave measurement of ice and water off the Labrador coast using the NASA/MSC radiometer as well as USCG studies illustrate the potential of passive microwave radiometry for observing ice (74). The difference in brightness temperature between ice and water is very large (60 to 120°K), although both may be at nearly the same physical temperature. Figure 4.7-6 shows an aerial photograph of sea ice and examples of the output of a 22.2 GHz and a 15.8 GHz radiometer (79) when flown over an ice/water boundary.

An electrically scanning microwave radiometer operating at a frequency of 19.35 GHz (~ 1.55 cm), was flown in NASA's CV-990 aircraft (16). The experiment proved that the technique can be useful for mapping the extent and possibly the thickness of sea ice, independent of cloud conditions. There were a number of consistent features to be noted in the brightness temperature patterns of the data. (1) Relatively uniform temperatures were mapped over



Air Photo of Ice/Water Boundary Showing
Flight Direction and Ground Track



Passive Microwave
Radiometer Traces of
Ice/Water Boundary

Figure 4.7-6 Microwave Radiation Measurements of Ice and Water off Labrador Coast; April 20, 1966, NASA; CRREL/U.S. Army

solid pack ice (245°K); (2) Brightness temperatures were not noticeably influenced by the cloud cover; (3) Brightness temperatures decreased sharply as ice became very thin; (4) Brightness temperatures of about (110°K) were measured over open water.

These results tend to show that the determination of ice thickness may be feasible using passive microwave techniques. Other sources, such as the National Academy of Sciences report on the Useful Applications of Earth-Oriented Satellites (77), have stated that there appears to be little possibility that microwave radiometers can measure sea ice thickness. Reasons stated are that at microwave frequencies it is doubtful that the penetration depth can approach the total ice thickness. When the ice is many skin-depths thick, its radiant temperature will depend on surface properties rather than thickness. If the thickest ice were only a skin-depth thick, then the radiant temperature would continue to rise as the ice thickness increased from zero thickness to one skin-depth. However, sea ice differs from lake and river ice in that it can contain varying amounts of salt, depending on its age. This varying salt content will change the rate of radiant temperature increase with thickness. These changes cannot be predicted when the salt content of the ice is unknown.

4.7.5 Conclusions

The experience gained through studying satellite ice imagery provides the basis for specifying further spacecraft experimentation in the field. The polar orbiting Nimbus satellite system is not adequate to support sea ice investigations which require knowledge of ice motion and of distributions of discrete ice-water features. The high-resolution infrared system (HRIR) and the advanced vidicon camera system (AVCS) on board Nimbus, at best, during periods of unrestrictive weather, display only the most gross ice conditions or unusually large ice-water features.

With a ground resolution from space of 30 to 300 meters in the visible range, the necessity of conducting long-range aircraft reconnaissance flights to obtain ice information for forecasting purposes could be largely eliminated. Lower resolution, however, would not contribute much above what can be done using existing satellite photographic systems.

Coincident with improvements in resolution, the contrast or gray scale range of the photography should be improved. The presence of thin ice, or old ice with large meltwater puddles forming on the surface, cannot be detected with current visual sensors except in rare circumstances. The use of microwave and infrared sensor systems may prove most helpful under these circumstances. Microwave sensors may also be applicable to the detection of ice features in polar regions when cloud cover and the long polar night preclude visual surveillance for extended periods of time.

The use of color photography to study tonal variations in ice features would be of use, especially if obtained in conjunction with black and white imagery from the same vehicle. In polar regions, ice age and thickness are often determined by color. Particularly evident is the "ice-blue" color of thick winter ice which persists from year to year. This type of ice is very hard, usually a result of gradual cooling and compression processes.

Present sea ice programs are not designed to provide the methodical data collection needed for systematic investigation of sea ice dynamics. For this purpose, it will be necessary to repeatedly map, with remote sensors, an area of sea ice coincidently with the observation and measurement of ice motion, wind, and ocean currents, to determine basic interrelations of ice motion and deformation with the causal environmental factors. An understanding of the interrelations of the forces and processes involved will enable development or improvement in theoretical models which describe ice motion and deformation.

Ideally, surface mapping would be conducted from an orbital platform which could provide sequential coverage with good spatial resolution for extended periods over a broad region of the Arctic Ocean. In order to maintain continuity in observation, the orbital sensor used should be operational in any weather condition and during daytime or nighttime periods.

4.8 ICEBERGS

4.8.1 Introduction

Since the Titanic disaster in 1912, the U.S. Coast Guard as a part of the International Ice Patrol has carried out ice surveys. These patrols were initially conducted by eye from shipboard and later from aircraft, which often meant flying below the clouds at ~15 meters above sea level. Several planes were lost in collisions with icebergs. After World War II, radar was used, again first from low altitude and as a safeguard for the ice survey planes. Since 1962, the Coast Guard has flown radar scanning systems installed in C-130 aircraft. The possibility must be investigated that this difficult operation could be conducted from space.

4.8.2 Data Acquisition Programs

Although the U.S. Coast Guard has been carrying out experimental programs in remote, all-weather sensing of icebergs in the arctic and sub-arctic since 1967, the principal inputs to their present iceberg location and tracking program are from Coast Guard ships and aircraft, and radio message reports of sightings from the U.S. Navy, merchant shipping and the Canadian Department of Transport. These reports are said by the Coast Guard to meet their requirements. The principal problems with reports originating external to Coast Guard are with misidentification and position error. The geographic coverage of the existing reporting programs, in the arctic, subarctic and Newfoundland area are of sufficient scope for the need, but the frequency of reporting is insufficient. The system as it operates requires at least daily reports and position accuracy to 8 km, which apparently are not achieved. The Coast Guard would like to receive reports within 24 hours of measurement (not achieved) and preferably, within six hours.

4.8.3 Significant Aircraft Experiments

A microwave radiometer, designated AN/AA2-23, developed by Sperry Microwave Electronics Company for the U.S. Coast Guard was installed in their C-130 aircraft for use in spotting and tracking icebergs. The radiometric design was chosen to provide both accuracy and all-weather capability for the service's international ice patrols.

Radiometry is a passive measurement, in contrast to radar, which requires transmission and reception of a signal. The radiometric unit is basically a sensitive, low-noise receiver which picks up the electromagnetic energy emitted and reflected in the microwave region of the frequency spectrum. The incoming signals are compared to a low-level energy reference source - said to be unique to this unit - which comes from a built-in automatic gain control. The difference between the generated reference and the incoming signal is measured and calibrated in degrees Kelvin.

By pinpointing the radiated energy source and magnitude, and recording them in coordination with the aircraft's speed, direction and altitude, technicians can measure such factors as size and shape of an iceberg, its rate of melting, the direction of its migration, speed through the water, and even whether the snow on the surface is new or old. Most important, the observer can distinguish between an iceberg and a ship, even in severe weather. For the most part, only the portion of the iceberg above the water produces a reading, although the radiometer does pick up signals from that portion not more than a few inches under the surface.

The Coast Guard reports achieving a spatial resolution of 10 m (analog) with this system under ideal conditions with an aircraft flown at altitudes ranging from 120 to 900 meters in the Grand Banks-Laborador areas in 1967-1968.

Bradie, in a paper presented to the ASP-ACSM in 1967 reported the identification of trapped icebergs in sea ice by use of Side-Looking Airborne Radar (SLAR). The brightness of their returns and irregular shapes led to the conclusion that they were bergs and not portions of a pressure ridge. The equipment in use was not described.

The U.S. Coast Guard reports experiments were conducted with the AN/DPD-2 (mod) SLAR mounted in the NASA/MSC aircraft in the U.S. /Canadian arctic and subarctic in the summer 1969 (72). At altitudes ranging from 1500 to 2400 meters they achieved spatial resolution of 30 meters in the case of sea ice but did not report on resolution obtained on icebergs.

4.8.4 Significant Spacecraft Experiments

Zaitzeff and Sherman reported (162) ice surveillance by IR techniques from spaceborne sensors. An iceberg estimated to be 115 kilometers by 32 kilometers was photographed twice, eight days apart, in the Weddell Sea (antarctic) with the NIMBUS I HRIR and AVCS. This is the first known case in which an iceberg has been photographed from a satellite over the the arctic or antarctic.

4.8.5 Conclusions

The Coast Guard has stated that resolution currently obtainable from space with AVCS data is not sufficient for identification and tracking of icebergs; they cite a need for 15 meters resolution. It has been forecast that if such resolutions could be achieved from space systems a reduction or possible elimination of aerial iceberg patrols might result (19). This resolution from operational systems is not, however, expected in the near future.

4.9 HEAT/ENERGY EXCHANGE

4.9.1 Introduction

The thermal status of the earth's oceans is a major factor in controlling the weather. Since the ocean temperature is not changing appreciably the energy lost must be therefore equal to that received. For example, the average loss of energy due to evaporation is 54% of the total received and the loss due to reradiation is 40%. The remaining 6% is carried by ocean currents from lower latitudes to polar regions where it warms the air above the water.

The heat of evaporation lost by the oceans is returned to the atmosphere in water vapor through the heat of condensation released during cloud formation usually at some area remote from where it originated. The oceans and the atmosphere, because of the effects of absorption of the ocean of energy from the sun, the evaporation of sea water and its later condensation into rain, reradiation of solar energy from the ocean to the atmosphere, and transport by atmospheric and oceanic circulation constitute a heat engine. This heat engine determines geographic climate (the mean or average condition) and weather (departure from the mean) on the earth.

Weather forecasting at present is done without direct knowledge of the heat flow from the world's oceans. Thus, we are operating without direct knowledge of the energy variations in time and geographic location which are basic to weather. World-wide synoptic knowledge of the daily energy release from the oceans would provide weather forecasters with this controlling factor.

4.9.2 Heat Flow Studies Using Aircraft

For the past several years E.D. McAlister and W. McLeish (63, 64, 65) have been developing an infrared radiometric system for direct measurement of the total heat flow from the sea surface. No other direct method has previously been demonstrated. The method entails the remote measurement of the vertical temperature gradient in the top 0.10 millimeter of the sea surface. This temperature depends on the physical and optical properties of water, namely its molecular heat conductivity and absorption coefficient for infrared radiation.

These measurements are accomplished with a two-wavelength infrared radiometer, operating in the 3.5-4.1 and 4.5-5.1 μ band, designed specifically for this purpose. Using the temperature gradient obtained and the conductivity of sea water the total heat flow may be determined.

This system was tested in May 1969, during the conduct of the Barbados Oceanographic and Meteorological Experiment (BOMEX) (64). A series of flights were made around Scripps' oceanographic vessel FLIP on which was recorded the vertical profiles of temperature and humidity above the water, along with other meteorological and oceanographic data. In this test successive 30-second flights were made upwind 300 meters north of FLIP and then downwind 300 meters south of FLIP. Separating the data for the north area and the south area for May 27, 1969, the following analysis was obtained.

Area	Heat Flow cal cm^2 min^{-1}	Sea Surface Temp. °C
N	0.40 $\pm$ .05	27.691 $\pm$ .018
S	0.50 $\pm$ .06	27.700 $\pm$ .024

0846 to 0952 27 May 1969

The average temperature at .075 mm depth over these 1.6 km strips is remarkably constant during the 66 minutes elapsed time, especially when it is noted that these values are as observed at altitude, i.e. part of the variation is due to atmospheric losses.

The present system has demonstrated the feasibility of airborne measurements of total heat flow from the sea surface. Laboratory tests show an average error of $\pm 8\%$ in measuring heat flow. This is the first time that such direct measurements have been made (65).

A new order of accuracy in sea surface temperature measurement has also been shown. The present system has surpassed the accuracy of oceanographic mercury thermometry for ocean surface temperature and it approachs 0.01°C. Precision measurements of the emissivity of the present internal blackbodies may show that the present system under limited conditions can make measurements of the absolute temperature of the sea surface.

4.9.3 Conclusions

Even though the infrared radiometer technique provided excellent results in the BOMEX test, the present instrument appears to be limited in its versatility due to atmospheric attenuation. The instrument must be flown at very low altitudes ($\sim$ 200 m). Microwave radiometry has been shown by McAlister to be also theoretically capable of the remote measurement of the heat flow. However, a significant increase in the state of the art of microwave radiometers is required to provide data to the accuracy required for heat flow measurements. Thus, it appears, that for the near future, the direct measurement of heat flow from either high flying aircraft or spacecraft is beyond the state of the art.

4.10 OCEAN COLOR

4.10.1 Introduction

The color of ocean water is one of the fundamental measurement parameters of the ocean and concurrently is amenable to measurement by remote sensing techniques. The distinctive color of various bodies of water is a familiar observation, however, of greater importance are the very slight and constantly changing color differences that occur within large bodies of water and may relate to anomalous conditions.

Water color has been used in the past and is presently under increased study for the measurement of the oceans' biological activity. In addition it now appears possible to distinguish different water masses, detect pollution, and determine water depth by accurate ocean color measurements.

In this section the effects of the atmosphere, water surface, and bulk water as they influence water color measurements are discussed. Recent progress towards obtaining true color response using remote sensors is documented. The detailed relationship of color to various ocean phenomena is included in that section that applies to the pertinent phenomena and thus is not discussed in detail in this section.

4.10.2 Ocean and Atmospheric Characteristics Affecting Signatures

Light irradiating the sea surface undergoes reflection and refraction. The reflected portion is polarized such that the component of the electric vector parallel to the sea surface predominates in the reflected light and, at Brewster's angle, is virtually the only component present. This can be made use of to select either the reflected skylight or the backscattered sunlight upwelling through the water surface, depending on whether the desired information relates to the shape of the reflecting surface or to the optical properties of the bulk water. The refracted portion penetrates the sea and, in the absence of scattering, is eventually extinguished by absorption. In reality, the light is scattered by particles of all sizes, from molecules through the larger colloidal particles and up to large bubbles or, in shallow water, by the bottom. On the high seas, about 5 percent of the incident light is backscattered upward toward

the sky. This is about equal to the skylight reflected at near-incident angles and severalfold larger than the fraction of reflected light passing through a suitable oriented polarizing filter.

4.10.2.1 Atmospheric Influences

Solar energy, upon reaching the top of the atmosphere, is transmitted directly downward through the atmosphere, scattered, absorbed, and reflected both directly and diffusely from the surface. It enters the water where it is scattered and absorbed and part of it reenters the atmosphere where it is again affected before it reaches the measuring instrument.

In the visible part of the spectrum (≈ 0.4 to $0.7\ \mu$) the atmosphere absorption of the solar energy is not a major factor in determining spectral extinction, but it cannot be ignored completely. Ozone, oxygen, and water vapor all exhibit some absorption in or near the visible spectrum.

The more important influence on the spectral nature of the radiation coming through the atmosphere is scattering. Besides primary (single particle) scattering the effect of secondary (light scattered by multiple particles) scattering must be considered in order to accurately account for the nature of the measured radiation.

In addition to the scattering phenomena there is also a polarization of the scattered radiation. This polarization of the measured component of radiation that comes from the atmosphere may provide a clue to the type of scattering occurring and indirectly to the effect of the atmosphere on the measured ocean color.

Previous studies have indicated the many problems involved in the prediction of the effect of the atmosphere on the spectral extinction of radiation. For very high visibilities, the attenuation is molecular and follows the λ^{-4} relationship of Rayleigh, and therefore the atmospheric effects are easily calculable. The introduction of an aerosol in the atmosphere, with its distribution of various sizes, results in spectral extinction that is difficult to determine.

More measurements have been made over continents than over oceans, but it appears that the aerosol elements to be found, especially over water

areas far from land, are sea-salt particles with a relatively simple distribution. The extinction experienced over coastal waters is more complex. A combination of both continental and maritime aerosol distributions appears to be needed to fit the measured extinction data.

The problem arises, then, in determining a way to adjust the ocean color measurements to account for any selective extinction and scattering of the atmosphere. Two types of measurements suggest themselves for determining the aerosol and thus making the appropriate adjustments. One is a measurement of the visible extinction of the atmosphere and the other involves the measurements of the polarization of the scattered solar radiation. A discussion of these measurements can be found in the TRW report: Study of the Remote Measurement of Ocean Color (104).

4.10.2.2 Water Surface Characteristics and Influences

Upwelling natural light from the sea during daylight originates from scattering within the sea, reflection from the sea surface, and reflection from the sea bottom if the water is shallow. The spectra of upwelling light will depend on many factors, one of which is the ocean surface condition. The backscattered light is nearly independent of the presence of waves; this is not true, however, for the radiation reflected from the surface of the sea. The surface reflected light is composed of two distinct types of radiation: 1) the specularly reflected sun's rays and 2) the diffuse skylight reflected at the sea's surface.

The intensity of upwelling due to the sun's glitter on the sea surface can be determined from the distribution of wave slopes of the surface, which depends on the wind speed, and the reflection coefficient, which in turn depends on the angle of incidence and the spectral region of interest. The brightness due to direct reflected sunlight is several orders of magnitude greater than scattered radiation; therefore, spectral information from sunlight scattered from particles beneath the sea surface cannot be obtained while the sun's glitter on the sea surface is within the sensor's field of view. If a sensor is pointing in a direction around the nadir, measurements when the solar zenith distance is small (< 30 degrees) are undesirable.

The reflected skylight for a particular field of view of the ocean is proportional to the intensity of the skylight from the appropriate portion of the sky. The skylight intensity varies over the sky and is a function of the solar altitude. For a sensor viewing around the nadir, only the zenith skylight is of importance.

4.10.2.3 Water Characteristics and Influences

The clearest waters from either fresh water lakes or the oceans have a deep blue color. This color can be attributed to the selective scattering of light by small particles and water molecules. The path length is quite long, with a dominant wavelength of 0.4 μ. The blue color gradually changes to a green color as the productivity of the water increases. This change is due to the addition of yellow substances that are directly related to the organic material contained in the water. In addition, some estuarine waters and inland waters are brown and red due to special conditions of the land run-off. As a result, the transparency of the water is much decreased and the dominant wavelength shifts through green into the yellow (at .57 μ) or even into the brown. Therefore, the color of ocean water is a measure of the productivity of water.

Ocean waters have been categorized according to the transmission characteristics of visible light. Table 4.10-1 lists the wavelength of maximum transmission and the percentage of light of this color transmitted in five different types of ocean. Roughly speaking, sea water is translucent for visible radiation only, and most penetrable for just the wavelengths that are useful to plants. In general, the less clear the water, the more the shifting of "surviving" wavelengths toward the longer waves, the green and yellow.

4.10.3 Determination of Optimum Spectrum for Sensing Ocean Color

Most aerial photography for oceanography has been based on procedures developed for terrain recording. While satisfactory for recording the water surface and a degree of subsurface information, this procedure does not fully exploit the potential of the photographic process for acquiring the maximum of underwater data. Studies have been conducted to delineate more precisely those films, filters and data processing techniques that should be used to obtain the maximum amount of information from ocean color (113, 141, 163).

Table 4.10-1. Wavelength of Maximum Transmission and the Percentage of Light of This Color Transmitted in Five Different Types of Ocean (77)

Types of Ocean Water	Wavelength* of Maximum Transmission	Percent Transmission Per Meter
Clearest oceans	470	98.1
Average oceans	475	89.0
Clearest coastal	500	88.6
Average coastal	550	72.4
Average inshore	600	60.8

*Given in millimicrons

Investigators have recommended photographic band pass filters for deepest water penetration which pass a relatively narrow band, approximating .50 to .57 μ, with peak transmission in the green, around .53 μ. The position of this band in the visible spectrum is shown in Figure 4.10-1 (57). This figure also shows attenuation curves developed from six sources, and illustrates the extent of the attenuation variability and thus color variability in different types of ocean water. All sources show attenuation rising sharply around .58 μ, and generally decreasing rapidly below .50 μ. The most fruitful region for deepest clear water penetration; i.e., least light attenuation, is according to D. Ross (113), below 0.50 μ; however, the trend has been to exclude this region based primarily on the manner of image analysis. W. Vary (141) has found that, with the use of certain interference filters, the 0.56 μ portion of the spectrum obtained the best water penetration and ocean bottom detail. E. Yost (160) also found the green part of the spectrum to be optimum for water penetration. Additional discussion on this subject can be found in Section 4.11.

Most interpretation of Earth sciences photography depends on visual means, where detail must have sufficient contrast with its surroundings to be detected by the eye. It is natural to select as best those images where detail is most easily seen.* Underwater subjects generally have more visual contrast when recorded in the green spectral region; and even higher contrast in the red record, within the shallow penetration permitted in this band. The more rapid the rate of spectral attenuation in clear water, the higher the apparent visual contrast becomes. And, of course, natural color films are made to record scene color luminances much as the eye would see them. Lepley (57), for example, in a qualitative visual analysis of 92 oceanographic Gemini color images recommends the use of minus blue filters, essentially to increase visual contrast.

*Visual interpretation is not likely to be supplanted by automation, but for quantitative data reduction, increasing use will be made of optical, electronic and computer aids for enhancing and measuring visually undefinable image information. Thus it is important to record as much information as possible in the spectral region of interest for processing by nonvisual means, even if it is not visually discernable in the original record (113).

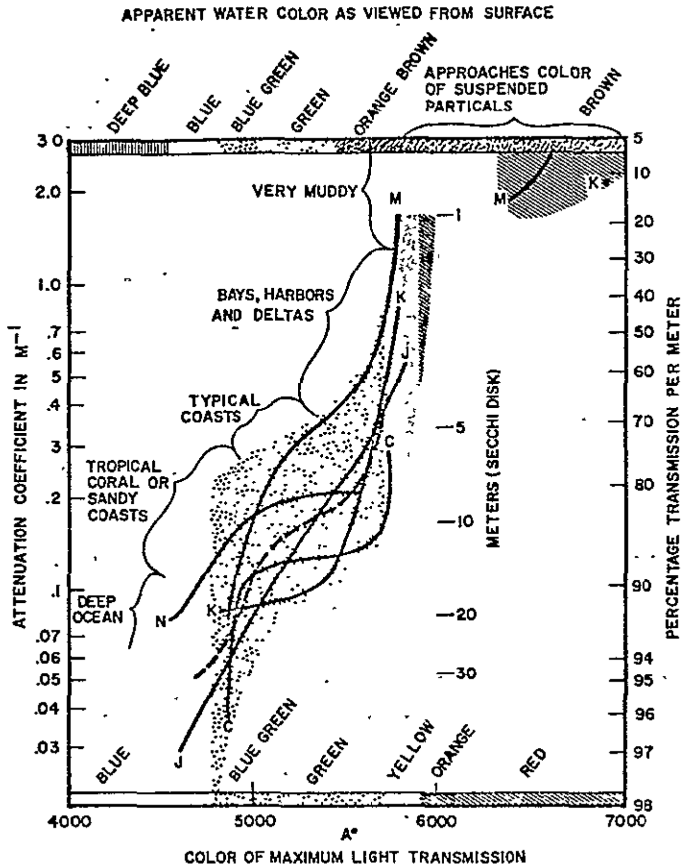


Figure 4.10-1 Light attenuation as a function of water color using various sources of information. Width of shaded band indicates approximate extent of data scatter and natural water variability (57).

In black-and-white aerial photography of terrain, light below .50 μ is generally suppressed with a filter such as the Wratten 12 (Minus blue) to minimize the effect of atmospheric haze in reducing image contrast. Similar approaches have been taken with color films for oceanography, by exposing the film through a Wratten 12 or 15 filter, or by completely omitting the blue-sensitive layer during manufacture.

As indicated by the above paragraphs, although the contrast of underwater detail is reduced by light scattering processes in the atmosphere and the water in the spectral region below .50 μ, the attenuation of light in clear ocean water is also at its lowest in this part of the spectrum. Consequently, the opportunity for deepest water penetration and the possibility of recording scattered light from the greatest depths occur in the spectral region below .50 μ (120). Broadening the pass-band would admit more energy and, in photography, would permit less-sensitivie, higher-contrast films to be used. However, the question remains: How much can the filter pass-band be opened in the blue region before the potential gain is offset by contrast degradation from scattered light in the atmosphere? Gemini and Apollo photography have served as a practical means of assessing the trade-offs (113). Thousands of images have been taken on the Gemini and Apollo missions with natural color films and a haze filter equivalent to the Wratten HF-3.* The HF-3 transmittance is about 80% from .43 μ to .50 μ, a spectral region where atmospheric scattering is high. The most useful images in natural-color films are those taken nearly vertical to the Earth's surface, since atmospheric haze increases sharply with obliquity, and is recorded by the blue and green sensitive layers proportionately.

Figure 4.10-2 shows the spectral attenuation of seawater, the relative transmittance of a number of filters, and an average curve for the blue-sensitive

*The color film haze filter used on many Gemini missions was the Hasselblad HV. On Apollo 7, a 2-E filter was used with 85% transmission of .45 μ. No filter was used with the hand-held natural color (SO. 368) on Apollo 9. On some missions, no haze filter was provided. Transmission of light at .45 μ in the types of lenses used is in order 60-70%. Average light transmission through the atmosphere for photographic purposes is in the order of 0.5 for the blue, 0.7 green, and 0.8 red (113).

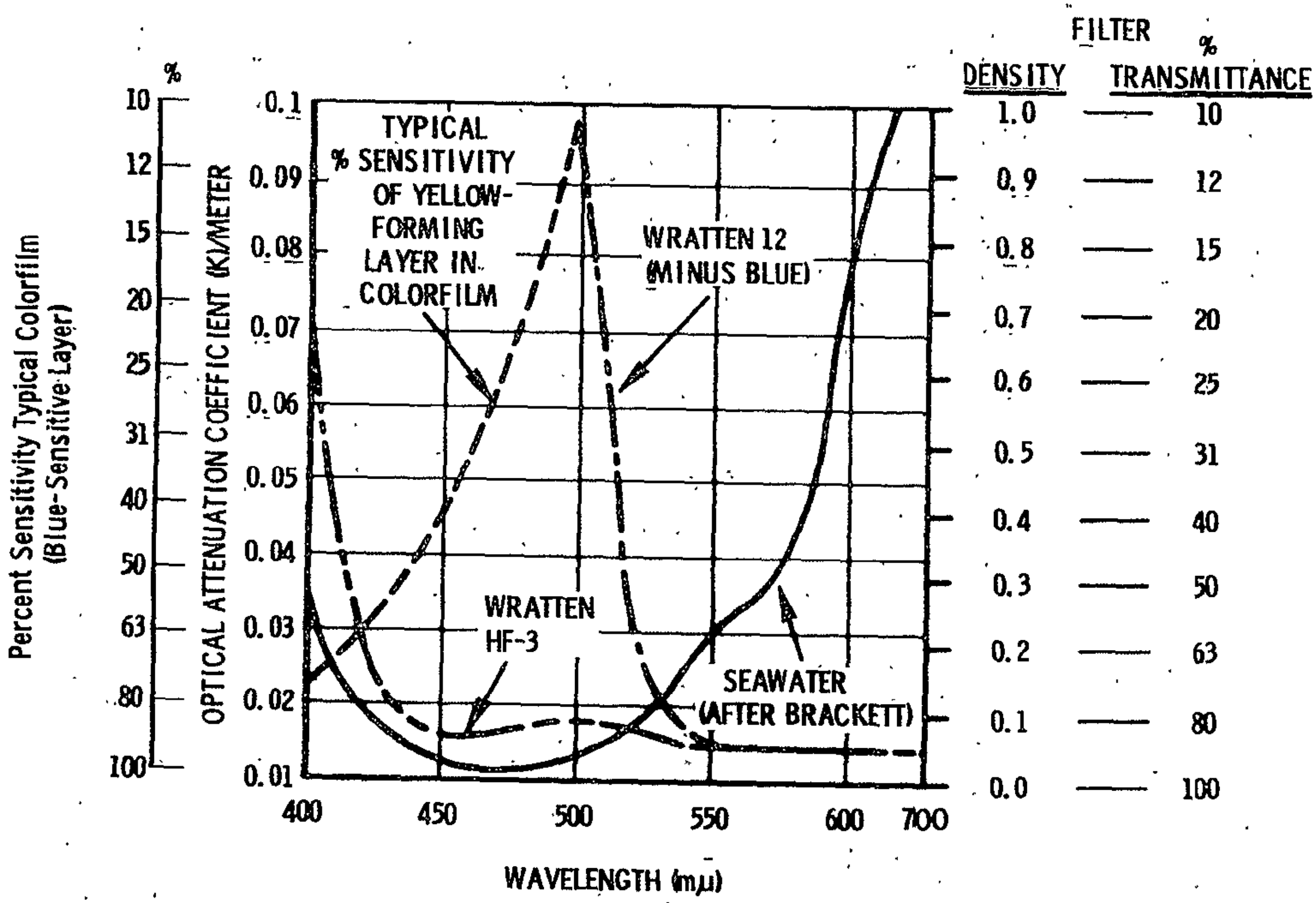


Figure 4.10-2 Light Attenuation of Seawater, Filter Transmittance, and Response of Colorfilm (Blue-sensitive) (113)

layer of a typical color film superimposed. (The blue-sensitive layer of most natural color films has a peak response around .40 μ, while the yellow dye-coupled image is peaked around .42 μ.)

Underwater information recorded in the blue-sensitive layer of the Gemini and Apollo film was isolated from the image by photographic color separation with a blue filter. It was found that this blue record generally contained as much useful subsurface information as the green record (113). As expected, the blue separation had a lower contrast. However, the contrast was raised during reproduction to that of the green separation for better visual interpretation. If interpretation is restricted solely to visual methods, much can be done in the laboratory to improve contrast through reproduction and enhancement processes.

Thus, the experience gained from the Gemini and Apollo images shows the filter pass-band for satellite color photography can be opened to at least .45 μ, possibly lower, without undue interference from atmospheric haze when sensing in the $\pm 35^{o}$ latitude zone of the Earth that has been photographed.

In coastal waters, particulate and organic suspensions in higher concentrations shift the band of best transmission toward the yellow-green, which is a spectral region of high clear-water light attenuation. Since many types of ocean water are found from frame to frame, or within the same image in the synoptic view from space, it is necessary to include this part of the spectrum within the single filter pass-band if it cannot be provided as a separate .50-.58 μ band.

It could be argued that light above .58 μ could be included, but other factors must be considered. Skylight reflected back from a calm water surface is in the order of 4-6% for solar elevations above 30^{o}. Light absorption even in clear water begins to rise sharply above .5 μ, while above .60 μ the attenuation of upwelling light soon falls to a level where it is indistinguishable from the surface reflection of skylight, as seen by the camera. So far as penetration and detecting low-order luminance differences are concerned, the reflected skylight component lowers the signal-to-noise ratio of the underwater scene. This is unavoidable, but if a spectral region is included where penetration is already minimal, more harm than good results, since the reflected skylight merely adds to the relative strength of the surface component throughout the whole pass-band while providing little additional subsurface information. It is therefore

desirable to record the spectral region above .58 μ with a separate filter band, for shoreline delineation and recording shallow features.

One significant experiment, conducted by Philco Ford (113), on contract to SPOC, had as an objective to photograph from aircraft a white, spectrally neutral target on the deck of the BEN FRANKLIN submersible at various depths. Comparison of the images and measurement of the photographic densities in each spectral band permitted assessment of the merit of each spectral band, for practical oceanographic photography.

The study concluded that information useful in oceanographic interpretations can be found in varying degree in each of the spectral regions currently planned for multispectral remote Earth resources sensing; essentially green, red, and infrared. However, unless a blue spectral record is also included, much oceanographic information of fundamental importance will not be obtained (113). The blue record combined with the green permits water color and its changes to be detected and evaluated. This part of the spectrum is where the color of the largest percentage of the world's oceans is found, where clear water penetration is greatest, and where small changes in color are related to major ocean phenomena.

It was therefore recommended by Ross (113) that;

1. Two spectral bands be used for oceanographic imaging, to be obtained with sharp cut-on and cut-off interference filters. Variation in the pass-band with angle is not of significance with lens field angles now contemplated for orbital sensors.

2. The two suggested pass-bands are .46-.51 μ and .51-.56 μ.

3. If it were only possible to have one camera, or imaging sensor, and one spectral band for oceanography, a single .46-.58 μ pass-band would produce the most information.

In studies conducted by W. Vary (141), he recommends, in contrast to Ross (113), the use of filters or film to eliminate the "undesirable" influence of blue light. To this end Vary originated a new non-blue sensitive aerial color film. This film has the red and green sensitive layers, a yellow filter layer, but no blue sensitive layer. The yellow filter layer prevents blue light from

reaching the red and green sensitive layers. Without the blue sensitive layer, the new film is blind to blue light and, therefore, aerial and underwater hazes are transparent to the film, blue imagery fuzziness is eliminated and no yellow filter is required over the lens.

Film with these characteristics was produced and tested to evaluate the green portion of the spectrum for water depth penetration by photometric techniques. Test results using various narrow band filters showed the most detailed imagery was to be obtained using the .56 micron filter. This was true for both shallow and deep water. The film recorded the ocean bottom at the 45 m depth.

The results of these investigations as well as those of Yost (160) appear to be somewhat contradictory, although all suggest acquisition of imagery in the green portion of the spectrum ($\sim .56\ \mu$). Designation of the blue spectrum, below $.5\ \mu$, by Ross and not by Vary may relate to the use of special processing and image enhancement techniques by Ross. Because of the importance of providing data in the optimum spectral regions additional detailed studies should be initiated to further study the advantages and disadvantages of potential bands.

4.10.4 Experimental Results of the Remote Measurement of Ocean Color

A number of investigators using various instruments (cameras, spectrometers, and spectrophotometers) have conducted experiments to study the remote measurement of ocean color. One of the more recently developed instruments is a widerange imaging spectrophotometer (WISP) developed by TRW. Data have been acquired over a number of areas with this instrument, including the Pacific and Atlantic Oceans and Crater Lake in Oregon (148). In all cases the measurements were made from altitudes of 300 to 3000 meters.

Figure 4.10-3 shows the spectral reflectance of two bodies of water noted for their clarity - the Gulf Stream and Crater Lake. The trend of the curves is similar and resembles the theoretical curve calculated by R. C. Ramsey (104). In clear water the scattering is due to the water molecules and is of the small particle or Rayleigh type. The light is scattered inversely as the fourth power of the wavelength, and is why clear water appears blue. At the longer wavelengths water absorbs virtually all the radiation entering it. The Crater Lake

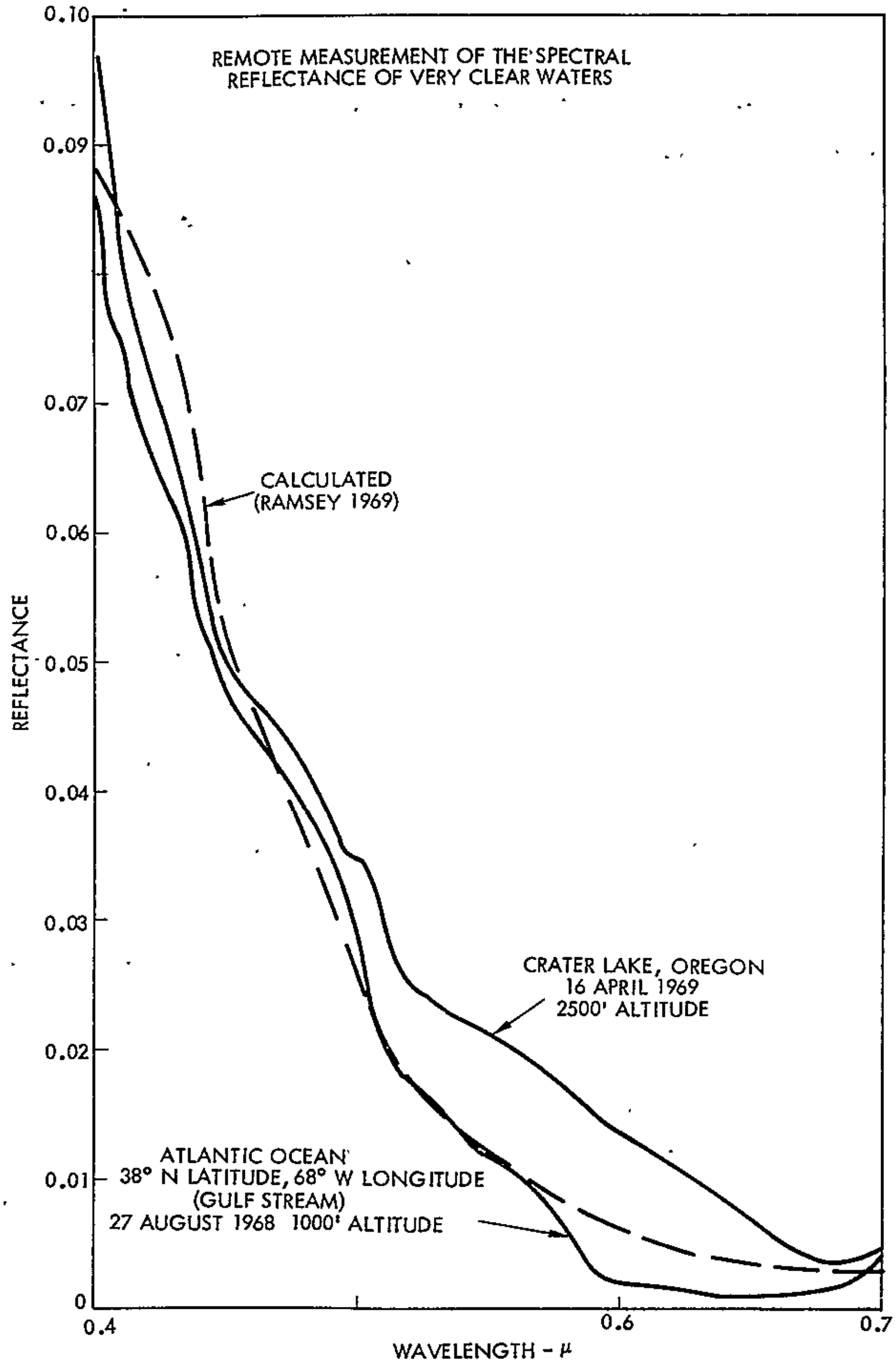


Figure 4.10-3 Remote measurement of the spectral reflectance of very clear waters (72)

water has a somewhat higher reflectance at longer wavelengths than did Gulf Stream water. This cannot be easily explained but is not inconsistent with measurements of transmission of Crater Lake water made by other investigators.

Figure 4.10-4 is the spectral reflectance curve of water containing a high particle content, in this case chlorophyceae or green algae. The reflectance has increased in the middle wavelengths due to large particle scattering. The chlorophyll a contained in the algae absorbs energy at 0.67 μ and this absorption is evident as a reduction in reflectance at this wavelength. The theoretical clear water curve is shown as a reference.

Measurements of the spectral reflectance of water with various chlorophyll contents are plotted in Figure 4.10-5. It should be noted the level of reflectance in this case is only estimated, although the relative values may be compared. Note also, that as the particle concentration increases, the reflectance increases at the middle wavelengths as in Figure 4.10-4, due to large particle scattering. The reduction in reflectance at the shorter wavelengths is probably an indication that the heavy concentrations of particles are near the surface. If they were covered by a layer of relatively clear water, one would expect a higher reflectance due to Rayleigh scattering by the water molecules. This would seem to indicate that it may be possible to estimate the depth of particle concentrations as well as their density.

Figure 4.10-6 shows the results of several spectral measurements made on a day with moderate haze from various altitudes. Unfortunately, no quantitative measurements of the atmospheric haze could be made. The general increase in reflectance is due to scattering by the atmosphere. Note that the general shape of the curves remains unchanged. There is some doubt as to the absolute levels of reflectance values and it is believed that the increase in reflectance at the long wavelengths is due to an unfiltered second order spectrum in the spectrometer.

The results shown indicate several characteristics of water spectra.

- High particle content increases reflectivity between approximately 0.5 and 0.6 μ.

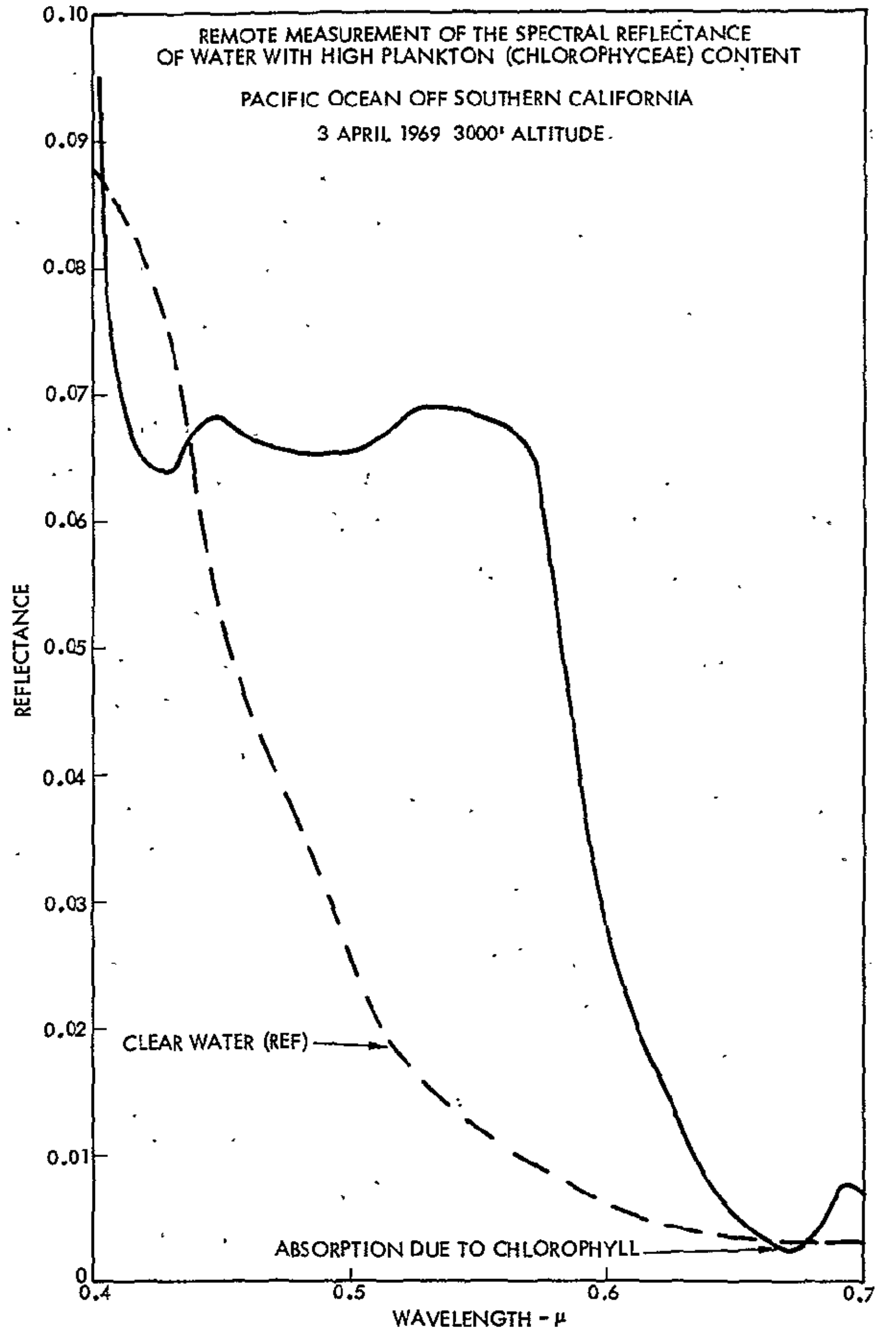


Figure 4.10-4 Remote measurement of the spectral reflectance of water with high plankton (Chlorophyceae) content (72)

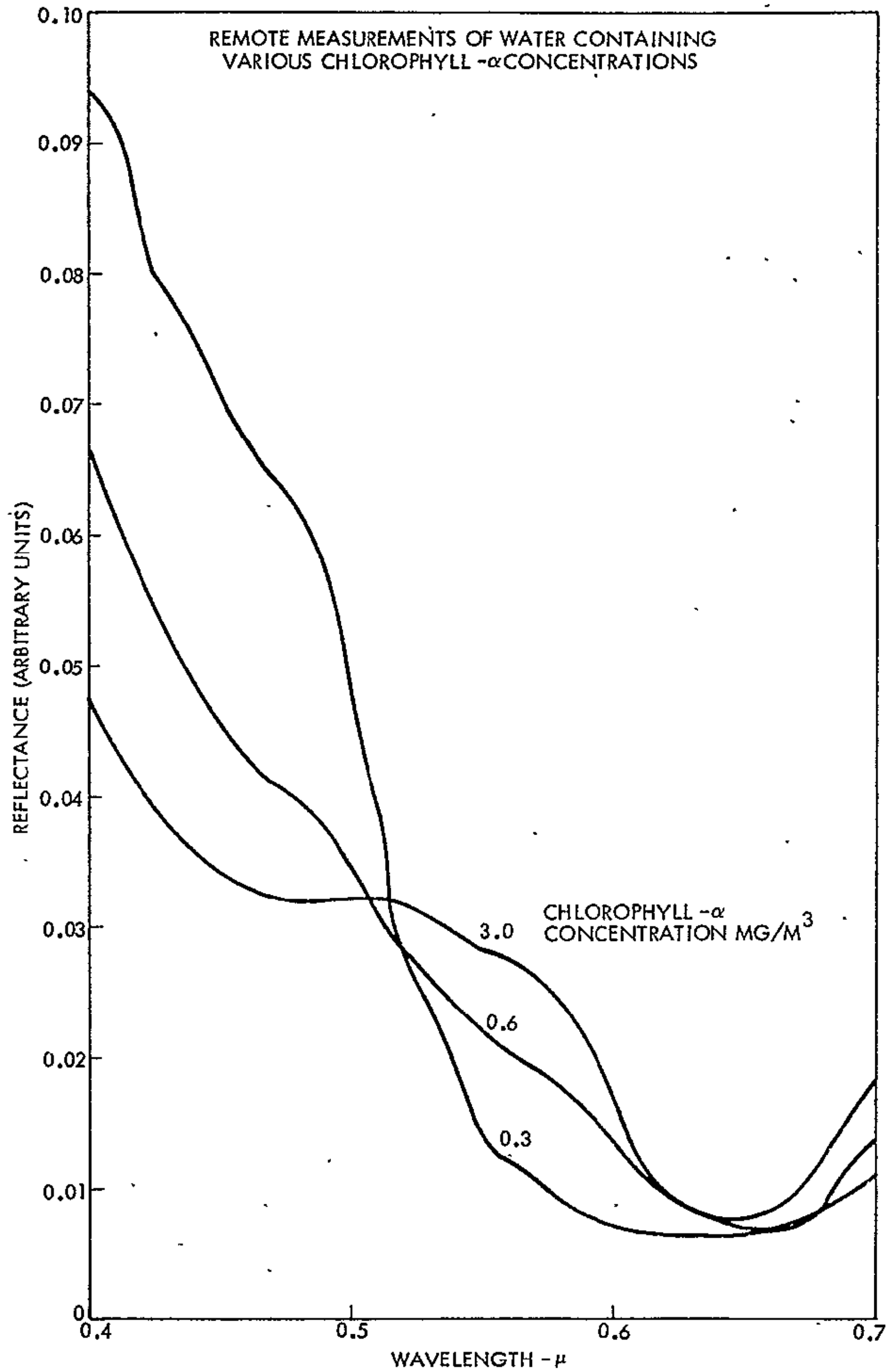


Figure 4.10-5 Remote measurement of water containing various Chlorophyllox concentrations (72)

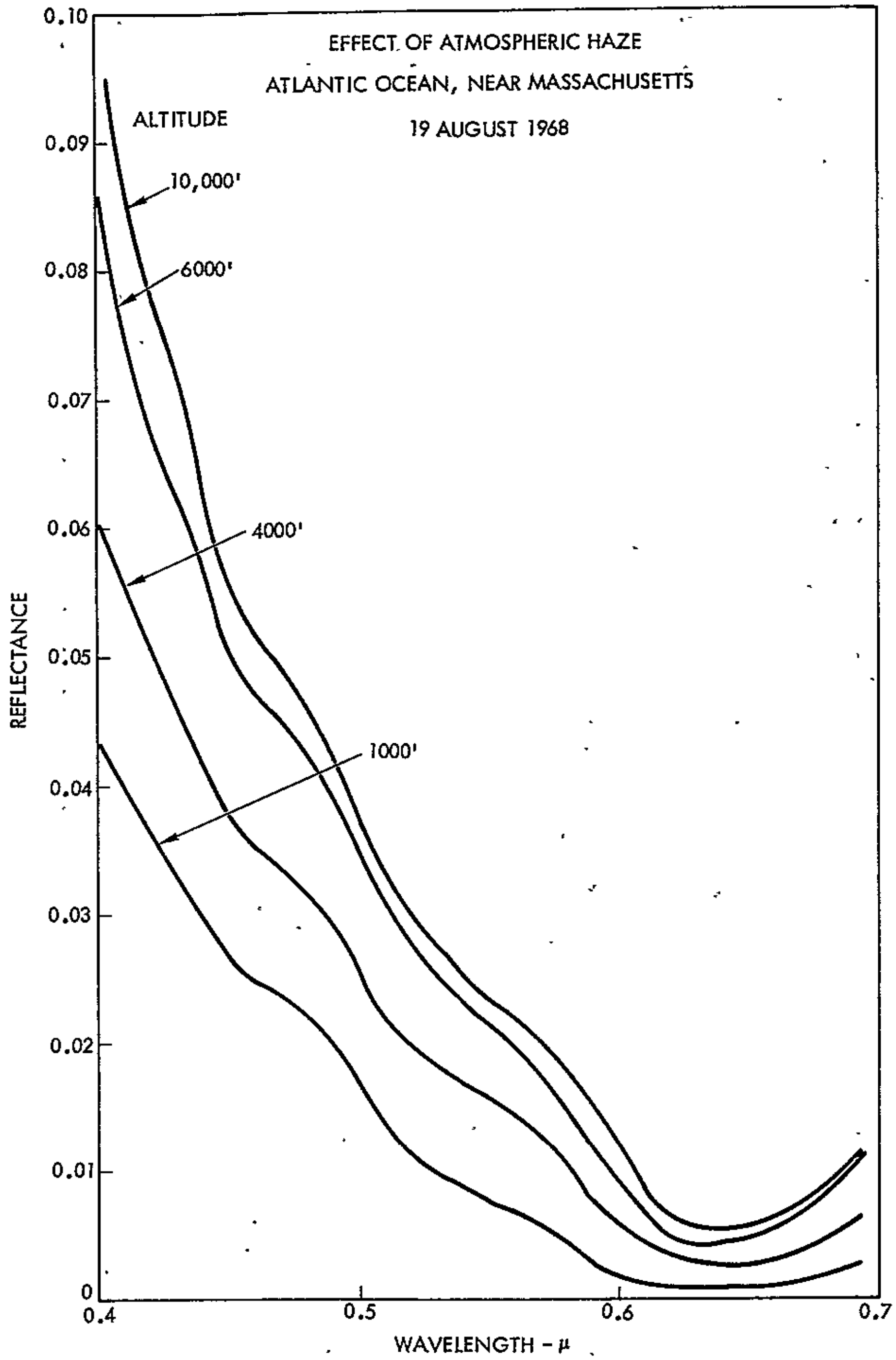


Figure 4.10-6 Effect of atmospheric haze on reflectance versus-wavelength measurements.(72)

- High particle content near the surface decrease reflectivity between 0.4 and 0.5 μ and increase it between 0.6 and 0.7 μ. This effect is minimized if there is a layer of clear water above the particles.
- Certain absorption bands can be recognized.

4.10.5 Relation of Water Color to Various Ocean Phenomena

The color of the ocean's water, as previously stated, appears to be a major descriptive parameter of the ocean. Thus, the accurate determination of the color will provide information to a number of user groups. Some of these applications are briefly discussed below. More extensive discussions are to be found in the appropriate section that addresses the phenomena.

4.10.5.1 Water Masses

The ocean's surface temperature is the only space measured parameter that presently serves as a discriminant of water masses. Thus, it is easy to distinguish the Gulf Stream water from the adjacent slope water by its temperature contrast (see Section 4.6). For more subtle differences, however, surface temperature is quickly altered by air temperature and by radiation, so that water masses having very different histories can have identical temperatures. As an alternative to the correlation of temperature and salinity, it appears that the correlation of temperature and color (see Figure 4.5-6) might serve to distinguish different water masses.

4.10.5.2 Chlorophyll

Most of the upper ocean is thermally stratified, thus it is sterile and blue in color. When stratification is overturned, as by currents or meteorological events, nutrients and cold water are brought into sunlit areas where photosynthesis initiates a biological chain. This in turn gives rise to the accumulation of chlorophyll and other biochromes. In the usual case chlorophyll concentration varies from 1.0 mg/m^3 to 0.1 mg/m^3. Consequently an ocean color sensing system must respond to very low color contrast to be useful for chlorophyll

detection. Progress to date indicates that indeed these low color contrasts can be detected by remote sensing techniques. See Section 4.2 for recent progress.

4.10.5.3 Water Depth

Numerous attempts to determine water depths using aerial and space photography have been made. Penetration of water up to depths of 45 meters have been reported (141) using aerial color photography over clear water. Additional studies are now required over areas of other water types which have much less clarity. These include most of the world's coastal areas which are of primary interest. See Section 4.11, Bathymetry for more detail on this subject.

4.10.6 Conclusions

It is readily apparent that the accurate remote measurement of ocean color by camera or spectrometric techniques is well within the state of the art. The measurement of this parameter has application for the detection of several ocean phenomena. These are: water masses (Section 4.6), chlorophyll (Section 4.2), water depth (Section 4.11), as well as pollution (Section 4.3).

Large ocean currents such as the Gulf Stream have been identified with airborne color photography. Chlorophyll concentrations have been measured with an airborne spectrophotometer. Water depths, in several clear water areas, have been measured with color photography from aircraft, and shoal areas have been detected with spacecraft color photography.

Prior to the operational use of remote sensing techniques for this purpose, however, additional studies are required. For example, films, filters and spectral regions must be delineated. To date only the most basic of data printout techniques have been employed. Thus, analysis and display techniques must be improved.

4.11 BATHYMETRY

4.11.1 Introduction

The need for updating nautical charts to remove doubtful hydrographic data and for providing additional chart coverage at larger scales has been expressed by a number of users and user agencies (20). This activity is presently undergoing a metamorphosis because of the prospects of man's continued penetration into the sea and his greater usage of the sea floor. The use of remotely sensed hydrographic data has been considered by a number of investigators (42, 100, 101, 141) and it appears that such data may be obtained for selected shallow water areas up to $\approx$90 meters in depth.

One of the more promising techniques for providing useful hydrographic data from space is the measurement of ocean color. Other remote sensing techniques that may provide beneficial data for water depth determination are direct measurement of water depth by laser ranging; measurement of wave characteristics that exist over shallow water areas; and (of less promise) the measurement of thermal anomalies.

Most work to date has been with the use of multispectral color imagery to determine water depth. The reliability of color anomalies as indicators of depth, is influenced by the spectral quality of the sunlight, by suspended material, by bottom material type, by algae species present, by atmospheric attenuation, by water characteristics, and by water depth. These are briefly discussed.

4.11.2 Determination of Water Color and Clarity

As part of the inventory on the characteristics of shallow water and submarine features, documentation of water color, transparency, temperature structure, bottom type and color spectrum is necessary. Lepley (57) using unpublished Naval Oceanographic Data, has shown that the distribution of water color and relative water clarity can be obtained from Gemini photography.

The qualitative determination of water clarity from Gemini photography was done on the basis of 1) apparent water color and 2) the visibility of shoals through the water. The basis of the method of water clarity determination is

the relationship between water color and transparency. Comparing a derived curve of light attenuation as a function of water color to Gemini photographs, strongly discolored water was considered to be less than 5 meters in depth (approximately 70% light transmittance), deep blue water is greater than 20 meters in depth (92%), and all other intermediate water is between 5 and 20 meters in depth. In clear water, where shallow reefs extend many miles from shore, as in the Bahamas, the color of the sea floor can be seen through the water, and the water depth can therefore be estimated on this tonal basis. Along most coast lines, the shallow sea bottom was not seen due to the small scale of the Gemini photographs. The global distribution of coastal water clarity is summarized in Table 4.11-1.

Table 4.11-1. Global Distribution of Coastal Water Clarity (57)

Percent Transmission Per Meter	Percentage of World Coastlines	Where Found	Implications
0 to 70% (0 to 5 m)	15%	Near all deltas of major rivers draining humid areas (e.g., Louisiana, China)	Not amenable to optical methods of bathymetric survey to 20 meters Sonar needed.
70 to 92% (5 to 20 m)	50%	Coastal water in temperate and arctic regions. Found also in tropics where upwelling occurs (West Africa, West Coast of S. America, N.W. Australia).	Amenable to optical airborne bathymetric survey by laser fathometer to at least 20 meters depth.
More than 92% (over 20 m)	35%	Tropical and Mediterranean water in areas free from upwelling (Caribbean, Mediterranean, S.E. Brasil, Madagascar, East Australia).	Amenable to airborne laser bathymetry to over 40 m depth. Amenable to aerial photographic depth contouring to over 20 m depth.
More than 95% (over 30 m)	10%	Lesser Antilles, Eastern Mediterranean, Hawaii, S.W. Pacific Islands	Amenable to airborne laser survey to over 60 m depth. Amenable to air photo contouring to over 30 m depth.

It is indicated in the above table that where the water clarity indicates a depth greater than 5 m, coastal surveys of bathymetry out to 20 meters depth should use aerial photographs simultaneously with airborne laser fathometers. Aerial photography will enable synoptic depth contouring and shoreline mapping, and the pulsed laser will directly give a depth profile and extension to water depths and/or turbidity beyond photographic capability.

Lepley (57) summarizes that on a yearly average, 85 percent of the world's coastal water is sufficiently clear for the use of an airborne laser fathometer for mapping sea floor topography from shore out to at least 20 meters depth; 35 percent is clear enough for mapping by aerial color photogrammetry to at least 20 meters depth and for laser sounding to more than 40 meters; 10 percent is clear enough for aerial photography to more than 30 meters.

4.11.3 Significant Experimental Results

4.11.3.1 Color Photography

The feasibility of using spaceborne cameras to acquire hydrographic information has been demonstrated for oceanic areas where waters are transparent. Figure 4.11-1 is an illustration of a hydrographic survey chart superimposed on a Gemini V photograph, which was exposed over Rongelap Atoll in the Marshall Islands - an area noted for its clear water. The photograph was exposed from a near-vertical orientation so that the imaged islands match the islands on the corresponding chart; it is apparent that many of the charted reef lines do not coincide with the imaged coral reefs. This type of comparison technique could serve to identify charting problems in specific locations, and it could be used by survey ships as a guide for planning efficient re-surveys. The accuracy provided by such photography is sufficient to correct horizontal positions on very small-scale charts, but it is not satisfactory to correct large-scale charts, or to determine depth.

While aerial photography for coastal surveying and shallow water depth determination had been attempted prior to 1967, photography obtained on black-and-white films was of minimal use and that obtained with color films had been accomplished over scattered areas with non-color-corrected lenses so that there was very little correlation between films.

Figure 4.11-1 GEMINI V PHOTOGRAPH OF RONGELAP ATOLL WITH A NAUTICAL CHART OVERLAY (Photo: Astronauts L.G. Cooper, and C. Conrad, Jr. - NASA; Overlay, U.S. Naval Oceanographic Office).

Recently two comprehensive tests were conducted at Key West, Florida by the U.S. Naval Oceanographic Office (141). The first test in March 1967 obtained aerial photography employing various types of film to determine the accuracy with which water depths might be measured using photogrammetric techniques.

Using the color photography acquired from 1500 meters altitude, excellent bottom detail was recorded in calm seas on the shoreward side of the reef and the red, yellow, and white targets placed in water 3 to 10 meters deep were clearly visible. On the seaward side of the reef, the red and yellow targets at 15 meters depth and the red and yellow targets placed on the shoals at 65 meters depth were also clearly defined in calm seas. Good penetration was accomplished regardless of the color of the water. With photographs taken at higher altitudes, wave patterns were more predominant and these patterns interfered with water penetration patterns.

False color infrared film, exposed through a Wratten No. 12 filter, was also used and demonstrated excellent penetration and ocean bottom detail at 20 meters depth. Prior to the test, no penetration greater than three to four meters with this type film was expected.

Results were also obtained in rough water. When seas were 2 to 8 meters and the wind was twelve to fourteen knots, gusting to twenty knots, both the regular color and false color infrared film still recorded ocean bottom detail on both sides of the reef, including the shoals at 20 meters. More sun and wave interference was evidenced in these films due to the high seas but it was not excessive and this particular result verified that aerial color photography is practical for obtaining hydrographic data under adverse conditions of high seas and winds. From this test, it was concluded that in order to obtain maximum water depth penetration using photography the following factors must be considered:

a. The interference of blue light must be further reduced or eliminated; (see Section 4.10.3 for conflicting opinion).

b. More exposure is required for deeper water penetration;

c. More contrast is required for ocean bottom detail; and

d. The green portion of the spectrum yields more incident light reflected vertically from the bottom with the least interference of other light within the water.

These results agree with those of Yost (160) as well as those of Lepley (57). In Yost's studies on the quantitative measurement of the comparative penetration capability of selected filters the green spectral band had twice the water penetration of the red and three times that of the blue band. See Section 4.10.3 for a detailed review of studies to obtain optimum band for determining water depth.

Blue light scattering in the air is referred to as "aerial haze." Under the water, the blue light is the most scattered and least absorbed. This condition is referred to as "underwater haze." In "color-corrected" lenses, the blue light cannot be focussed at the same plane as the green and red light, causing fuzziness in the composite image. Blue light also lowers the contrast of a scene and, while the water is illuminated by incident light, it is also illuminated by skylight, which is predominantly blue.

To eliminate these undesirable effects of blue light, a new non-blue sensitive aerial color film was originated (141). This film has red and green sensitive layers and a yellow filter layer but no blue sensitive layer. The yellow filter layer prevents blue light from reaching the red and green sensitive layers. This film was first tested off the Bahamas in February 1968. Results showed the more detailed imaging to be obtained with a 0.56 micron filter.

Both the Anscochrome D-500 and the new non-blue sensitive films showed water penetration to 45 meters. However, the new non-blue film demonstrated the following advantages over the Anscochrome film (141):

a. Increased image contrasts;

b. Detail in terrain and in shallow water was retained when exposing for deep water;

c. An effective film speed of 1,000 which is 4 times faster than the Anscochrome D-500 exposed through a yellow filter; and

d. No yellow filter is required over the lens.

Since it has been verified that this type of photography will penetrate to 45 meters in fairly clear water, tests are necessary for other areas where the water is less clear. Photographic emulsions and techniques will need to be determined for optimum results for other water and bottom characteristics. Photography for categorizing the different waters is now being accomplished in the U.S. Trust Territory, Puerto Rico, Florida, Wallops Island, and Diamond Shoals areas.

Photographic film provides a convenient and operationally-simple means for recording, storing, and analyzing multispectral data spatially related to position with respect to the ocean surface. Photogrammetric calculations made from the photographic image plane would permit rapid hydrographic surveys of large or inaccessible areas by remote sensing techniques. Multispectral photometric measurements provide "color" information to assist the interpreter in accurately defining the land-water boundary, separating water-borne sediment loads from images of sand bars and reefs, achieving maximum photographic water penetration for bathymetric mapping, etc.

4.11.3.2 Multispectral Scanning

Another promising technique that may be used to map color differences and compute water depth involves the use of two or more channels of data that measure the spectral signature for each element observed under water. A sensor system that can implement this technique is under development by the University of Michigan's Willow Run Laboratories (101). This system presently obtains data in 18 channels spaced between 0.3 and 15μ. Data in the visible region are obtained simultaneously in 12 different regions between 0.4 and 1.0μ. The spectrometer mounted in the scanner represents certain advantages in spectral filtering over the use of color film in cameras because, with the former, a mechanical method is employed to select the wavelength interval, whereas with the latter, dyes and emulsions are used whose spectral responses are generally broadband and not well defined. The multispectral scanner is also advantageous in that the time and space synchronization for each resolution element is assured, thus permitting the use of automatic pattern-recognition schemes in the analysis of the large amounts of data expected to be obtained utilizing satellites or aircraft.

Illustrative of the type of data that can be obtained with a multispectral scanner are the images (showing bottom details) in Figure 4.11-2. This figure shows data from only a few of the channels in order to illustrate the effect of wavelength on the quality of the image. Note that the best detail is seen in the .55 to .58μ regions, while only land above the water surface or white foam, etc., are shown in the 0.8 to 1.0μ region. In the region 0.62 to 0.66μ only the shallowest points are observed, while in the blue region, 0.40 to 0.44μ, scattering of light tends to lower the contrast of objects beneath the water. Much work is being done to try to relate density on film to depths of water. The amount of light reflected back to the sensor is the product of several factors, including the transparency of the water and the reflectance of the bottom material. Therefore, one must be careful to distinguish a given density on film as the result of light coming either from a strong reflector at a relatively greater depth or from a weak reflector at a relatively shallow depth, both of which may give the same density. Only in the areas where bottom type and water clarity are uniform can there be a reliable correlation between density and depth of water.

The full potential of the multispectral method (besides the automatic recognition and the improved spectral filtering) lies in the possibility of computing absolute depth using two or more spectral channels. The results of preliminary processing of a small portion of data taken off the Florida reefs are shown in Figure 4.11-3. Two-channel processing using a light-pencil method was performed; this processing amounts to color recognition of underwater features using two spectral intervals. Comparison with the depth sounding shows that water depths of less than 4 meters were recognized.

A parametric analysis of an optical-mechanical scanner has been conducted by Willow Run Laboratories (101) to determine the requirements for obtaining data for water depth penetration and for mapping details of under-water features.

4.11.3.5 Laser Depth Ranging

Water depth appears to be determinable directly by use of an optical laser system which measures the difference between the laser-beam reflection from the water surface and reflectance from the bottom. A number of

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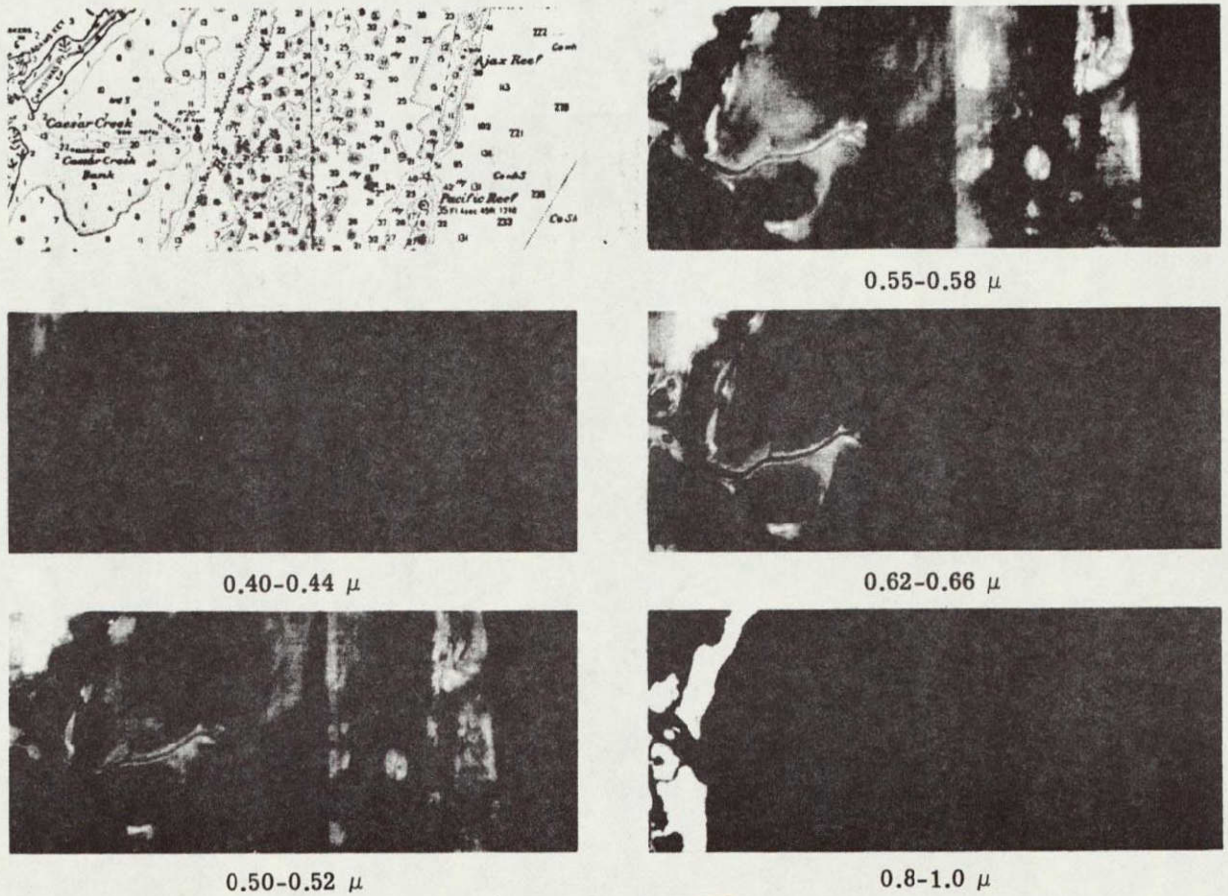

Figure 4.11-2 FIVE-CHANNEL MULTISPECTRAL IMAGERY, PACIFIC REEF, ALTITUDE 3000 m (101)

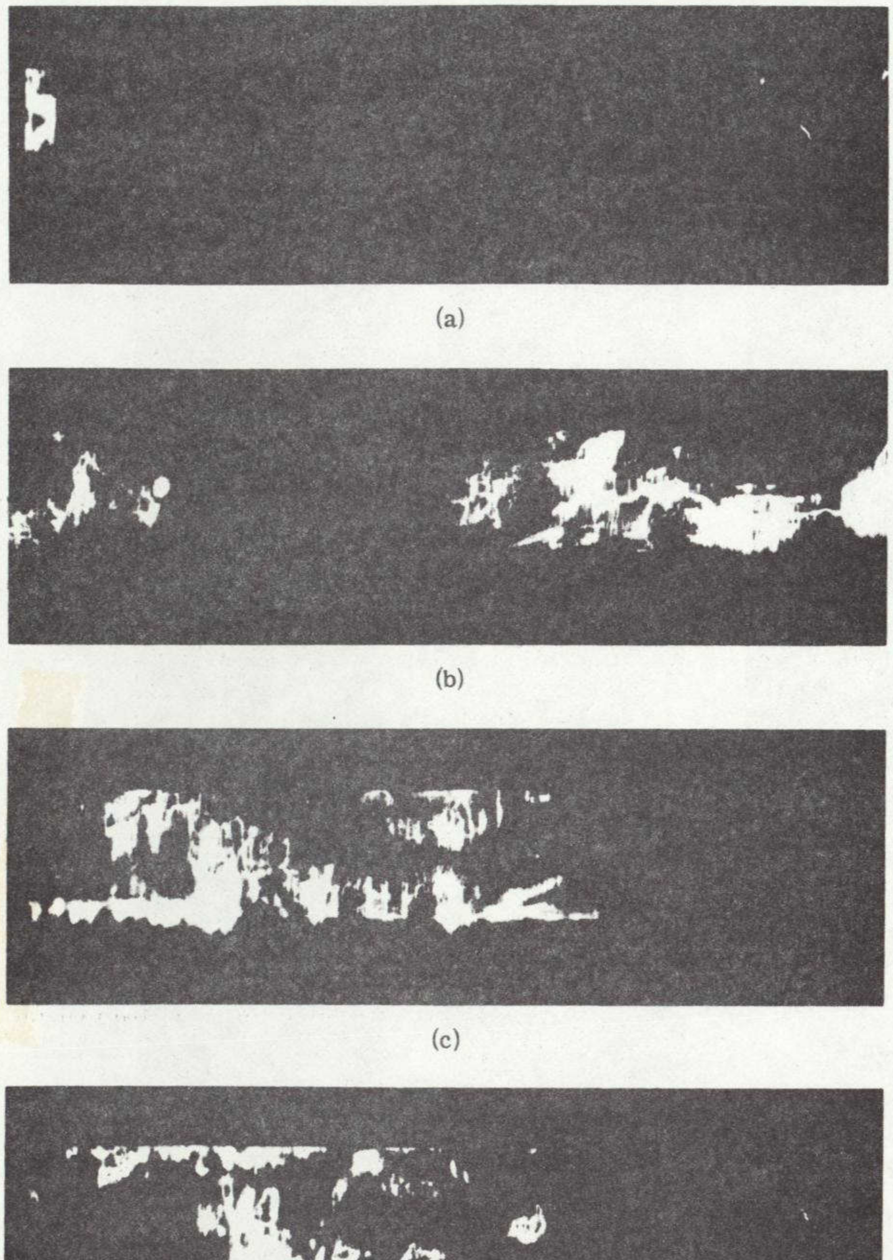

Figure 4.11-3 PRELIMINARY RESULTS OF ONE- AND TWO-CHANNEL PROCESSING. Three different underwater features are mapped in parts a,b, and c. (101)

investigators have studied this application, (42, 101, 106) to determine the feasibility. Two separate systems have been used in airborne tests, one built by Raytheon (106), based on a frequency-doubled yttrium aluminum garnet laser (5300 Å) transmitter and one built by AVCO (42), a Neon laser (5401 Å). Resolutions of the two systems equal 3 to 4 attenuation lengths which extrapolates to a maximum depth measuring capability of ~36 meters. Murky waters will reduce depths obtainable. It is expected that these figures can be increased to a point where 4 to 6 attenuation lengths can be achieved for airborne systems. At this point power becomes a limiting factor. In shallow water, a 0.5 meter accuracy in depth determination was achieved (106).

The bathymetric information from a laser system is obtained by measuring the time difference between the light which is reflected from the surface of the water and from the sea floor. The signal from the water surface is many times greater than the signal from the bottom because it does not suffer the attenuation losses of the light's double passage through the water medium. Thus it would be required only to investigate the signal-to-noise conditions which influence the signal from the bottom in order to determine the maximum depth-ranging capability of satellite and aircraft laser systems built using state of the art laser components. This has been done in a preliminary manner by the Willow Run Laboratories of the University of Michigan (101).

Figure 4.11-4 shows depth ranging system performance obtained by the University of Michigan using the design parameters developed for their study. The plot for the satellite system indicates a coastal-waters depth-ranging capability of 15.3 to 30.5 m for daylight conditions (noon) and 15.7 to 31 m for nighttime operation. All the systems studied showed a depth-ranging capability of greater than 10 m for the worst case (maximum attenuation coefficient) of coastal waters. For example, in Chesapeake Bay, the satellite system could measure a depth of 15.3 m. For the aircraft system, coastal waters depth-ranging capability under daylight conditions is 36.5 to 74.0 m at both $\frac{1}{2}$ and 10 km altitudes. (The system design for $\frac{1}{2}$ km altitude operation was optimized, by reducing the power of the laser, to make the performance equal to that of the 10 km altitude system.) For nighttime operations, the aircraft depth ranging capability in coastal waters is 45 to 90 m for the $\frac{1}{2}$ km altitude system and 46 to 93 m for the 10 km altitude system. Spacecraft systems would tend

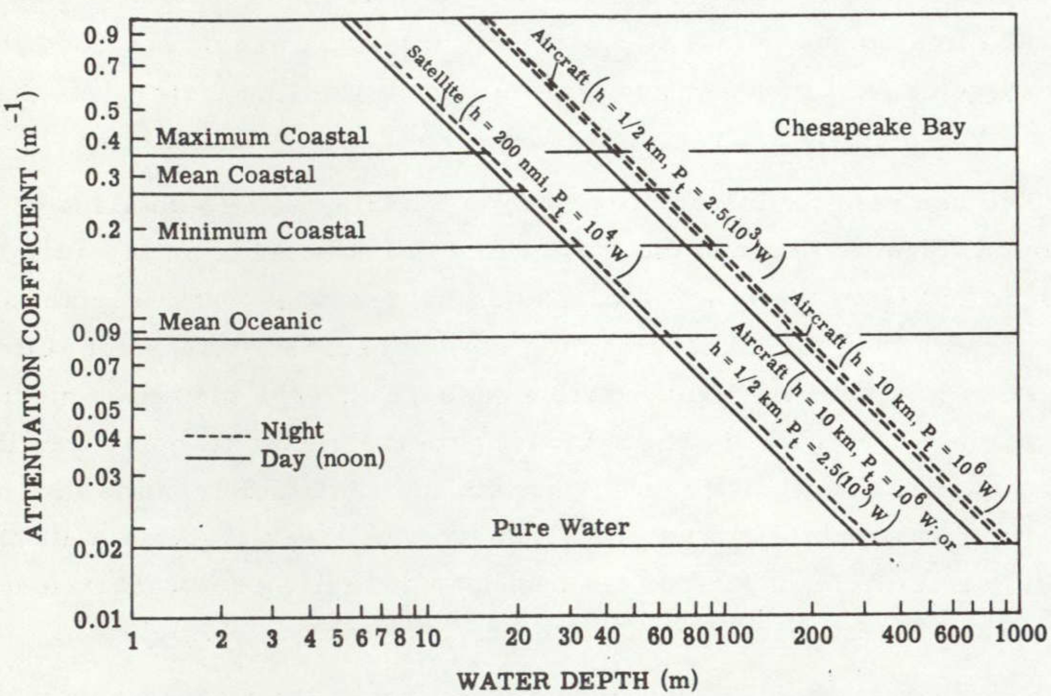

Figure 4.11-4. PERFORMANCE OF NEODYMIUM LASER RANGING SYSTEMS FROM AIRCRAFT AND SATELLITE PLATFORMS. P_t = peak power (101).

to be large, so that component and subsystem development must be carried out to assure that these systems are practical in size and reasonable in cost.

4.11.3.4 Wavelength Comparison

Investigations are being conducted at the University of Michigan (101) using waterwave refraction as a potential indicator of depth. This technique may prove to be significant for those areas where light penetration of water is poor.

The practical application of wave-refraction techniques to the detection of shoal waters will depend heavily upon the ability to image surface waves (for wavelength determination) from the aircraft or spacecraft and upon use of an optical correlator for wavelength determination. The application of an optical correlator will make it possible to semiautomate the decision process for the detection of shallow waters by using a variable-gate technique to determine the maximum wavelength of the ocean waves in the image field. The output from an optical correlator is a diffraction pattern (similar to an X-ray diffraction "powder pattern") that appears as dots in a polar-coordinate field. The dot spacing is dependent on wavelength, and the dot position is related to the azimuth direction of the impinging waves.

Possibly, the application of wave-refraction techniques to shallow-water location may only require determining whether a particular wavelength is present in one frame and disappears in another. In the optical processor, the Fourier transform plane is photographed, and a wave swell of a given length and direction appears as a point near the center of the transform on the film. The shortest wavelengths appear farthest from the center. The azimuth direction of the pattern is related to the direction of propagation of the wave front. In a preliminary test (101), a change in the Fourier transform was observed as a result of changes in the wave surface due to the presence of an island (see Figure 4.11-5). What is needed now is a series of photographs of wave refraction taken near shallow depths and then optically processed to measure the length of the refracted wave; the best analytical model studies can then be used to estimate water depth from the knowledge of deep-water and refracted wavelength.

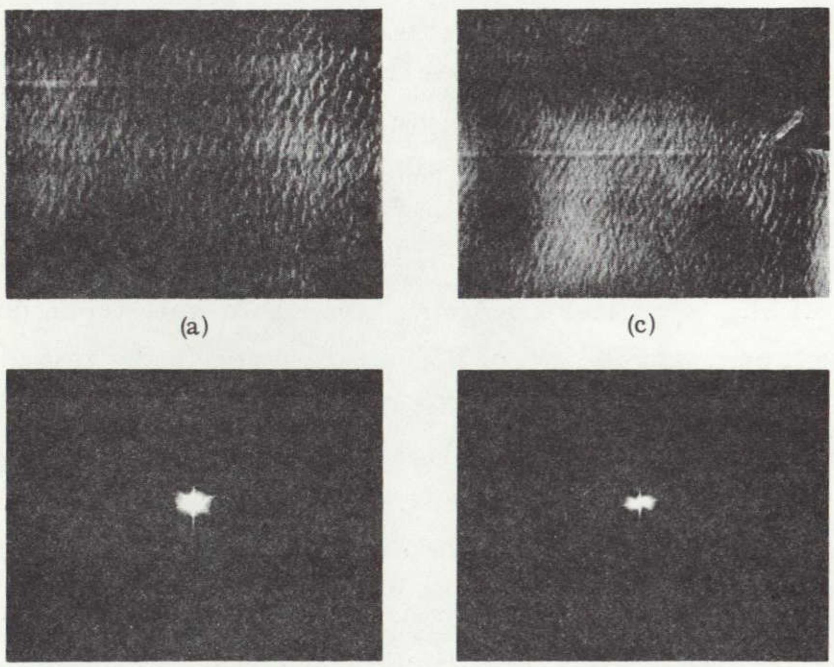

Figure 4.11-5 PRELIMINARY RESULTS OF OPTICAL PROCESSING SHOWING DIFFERENCES IN FOURIER TRANSFORM DUE TO THE PRESENCE OF AN ISLAND. Parts b and d are the transforms of parts a and c, respectively. (101)

The optimum application of the wave-refraction technique depends upon the existence of swells impinging upon a shoal feature. Since these swells are usually generated by storm activities at distances remote from the site of measurement, their form approximates that of plane waves. (Plane waves produce the most distinct "dots" in the optical correlator's Fourier component pattern.) Open-sea swells range in length from 90 to 250 m and occasionally they are as long as 360 m. (The record length is up to 1525 m.) When long waves impinge upon shoal water, they begin to feel bottom and to change their length and/or break. From the linear theory, an open-sea wave with a length of 225 m will reduce to 100 m when it encouters a depth of 8 m, if the swell height is not such that it has broken by the time it reaches approximately 15 m.

Contrast enhancement of waves is possible through the use of the different polarization properties of reflected sunlight and a changing water-surface slope. Imaging wave patterns by camera or by radar systems from space has one advantage over low altitude data in that the smaller scale leads to a Fourier transform where the longer wave-lenghts are separated further from the center.

In application, the maximum wavelength within a satellite's image field may be monitored by an optical correlation technique. When waves of lengths greater than 120 m are indicated, the maximum length will be monitored until a significant reduction of this length is observed in the field. This reduction may take place for any or all of the following reasons: 1) the sensor in orbit may be outrunning the direction of swell propagation from a storm center; 2) the orbit path may be toward the storm center; 3) the wave field may be encountering shoal water. The rate of change of the maximum observed wavelength and direction data from the optical correlator will give information concerning the direction of propagation. If it is suspected that the wavelength change is caused by shoal water, the multispectral "color" record will be examined for a color change, and the thermal record will be examined for a temperature change. Further, the wave record will be examined for direction changes indicating true wave refractions and for wavelength patterns indicating wave trapping of wave energy.

Detection need not be done in real time; multiple passes of a satellite can be used to establish the persistence of color and temperature anomalies

and to take advantage of the opportunity to observe the events of wave refraction in the case of swells arriving at the site from several directions.

4.11.3.5 Thermal Anomalies

Of all the observables under investigation the thermal anomaly appears to hold the least promise of positive association with submerged features (101) because of two limiting factors. First, depth of water cannot be inferred from the detection of a thermal anomaly, so the anomaly would be useful only as another indicator of geographical position. Second, there are many other phenomena which affect temperature structure in the oceans (e.g., upwellings, currents, and fronts), so that detection of a thermal anomaly may be a false indication of a hazard to navigation. Nevertheless, a study was made (101) in an attempt to determine if spatial extent of absolute temperature differences (or anything else) may serve to distinguish types of anomalies and therefore indirectly provide useful information about underwater features. It was encouraging that two examples of infrared thermal imagery showed apparent positions of underwater features due solely to the surface temperature structure. Infrared imagery acquired by HRB-Singer, Inc., showed that observed thermal variations correspond approximately to depth contours. Other imagery obtained by Naval Air Development Center, shows underwater features by the variation in the "spatial texture" of the temperature differences at the surface; i.e., one could not find a temperature gradient as such, but one could infer its existence by recognizing a change in the "thermal structure" on the infrared map. Conclusions resulting from a number of investigations have shown that anomalous heating effects do exist and might be detectable as surface effects, especially in the formations of new shoals or islands by volcanic action, but the technique has limited application.

4.11.3.6 Algal Type and Bottom Characteristics as Indicators of Water Depth

Other possible indicators of ocean depth (in coastal regions), include bottom type and algal type. Polcyn (101) disucsses the possibilities of using algal for depth determination pointing out that algae grow in all the oceans of the world but are restricted to more or less "shallow water" 200 meters. It is well known that those algae which are visible part of the time because of

tidal movement show marked zonation patterns. If algae which are always submerged are similarly zoned, then they may also be indicative of depth.

There are a number of multispectral sensors being developed, which could be used to recognize species by their spectral signatures; thus, if there were an ecological relation to depth, then the depth might be inferred from the recognition. Even if there were not a reliable relationship of type with depth, it still would be useful to know the predominant species in likely areas and then to use the change in the observed color of the algae (due to the spectral losses in the light with depth) as a measure of the depth differences. When-even a uniform bottom type is encountered over a varying depth, and uniform water transmission can be assumed, then a measure of depth change can be obtained from the change in density of a photograph or the change in electrical signal from a multispectral scanner.

Many ecological factors influence algal distribution. The following are the more important factors affecting distribution in the infralittoral fringe and in the infralittoral zones.

1. Emergence	5. Substrates
2. Light	6. Salinity
3. Temperature	7. Periodicity
4. Sea Activity	

Polcyn's conclusions (101) were that algae grow at specific depths depending on a number of ecological factors. Most depth ranges are relatively wide (up to 15 m), but a few algae in the infralittoral fringe are restricted to zones 1 m or less in width. In a few instances, algae types identified at the surface given an indication of depth; for example, the presence of the brown kelp Macrocystic implies depth of 10 to 25 m. Where a particular algae type grows at various depths, it becomes useful in terms of a known spectral reflectance percentage and thus aids in mapping features through multispectral techniques. The literature is inadequate in supplying necessary depth data for most areas of the world. It will be necessary to conduct studies specifically for the purposes of clarifying ecological changes with depth and compiling a catalog of indicator species and their ecological requirements.

4.11.4 Image Enhancement Techniques

Various image enhancement techniques have been under study for a number of years. These techniques are employed for the purpose of extracting additional information other than that readily detected by visual means. One process that shows significant potential for increasing the information content in photographs for hydrographic surveys has been developed by D. Ross (112, 113, 115). This process reduces each density level on the image sequentially into a form which can be printed separately on color-coding mylar base films, each level being represented by a different color. All densities in the continuous-tone density range of the original image above and below each density slice are completely suppressed. The color-coded density slices are assembled in register with one another to form a composite false-color transparency which may be viewed in this form; or individual "slices" may be removed from the image and re-assembled to show the patterns and contours of discrete brightness levels in the original image. The original image may be a standard black and white photograph or may be separated from natural or infrared color films with optical filters.

Where the bottom reflects light homogeneously, the luminance of light in clear water can be related to relative depth, as recorded by vertical photography, if densitometric characteristics of the camera and film are known and a standard atmosphere is assumed. Other factors such as particulate matter in the water introduce unknown factors which will influence light scattering and absorption, affecting the utility of this approach to bathymetry.

Examples of image enhancement are shown in Figure 4.11-6 and Figure 4.11-7. These figures show both shallow and deep water contours that were made from a Gemini photograph of the West Florida Keys. The shallow water enhancement method (8 increments, 7 at 0.05, the green contour at 0.10) produces nine meter depth contours which has close agreement with charted depth contours throughout much of the imaged area. There are several departures in the continuity which probably show where the water has deepened in some areas and become shallower in others since the bathymetric chart was produced. The 9 meter depth is mostly contained within the first three density levels (purple, red, orange). The outer contour line on the west and north of

Figure 4.11-6 WEST FLORIDA KEYS, SHALLOW WATER (115)

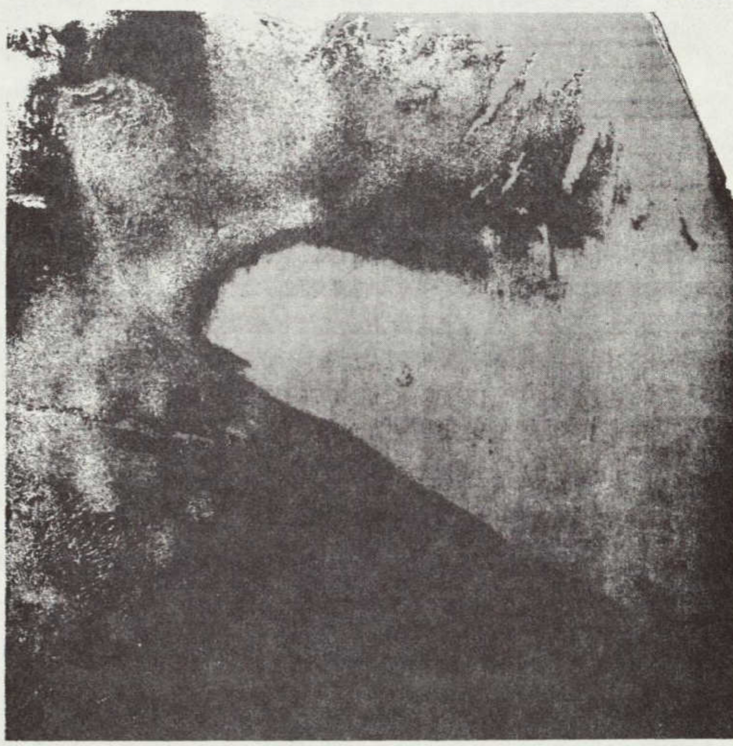

Figure 4.11-7 WEST FLORIDA KEYS, DEEP WATER (115)

this chart is at 18 meters, and includes an area noted "Shoaling, 1966," but depth has evidently not decreased as yet to 9 meters. In the deep water enhancement (eight 0.05 increments) depth contours correlate at a depth of 18 meters in this region in the western and northern quarter, but deviate in the northeast and southern areas.

Photo-optical image enhancement processes are important aids for interpreting oceanographic imagery. The geometry of the input image is preserved, visual resolution of detail is improved substantially, and low-contrast density and color changes can be separated readily. Reduction of the enormous quantities of data found in images of the earth taken from space can be accelerated by such processes on a rapid and economical basis.

Thus far, space oceanographic images which have been made available for image enhancement have not been entirely suitable for scientific work, nor were they intended to be more than preliminary records. Nevertheless, the potential which this form of remote sensing offers has been more than clearly demonstrated. Fully calibrated sensors and closely controlled image reproduction will permit quantitative measurement to be made of many forms of ocean phenomena.

4.11.5 Conclusions

Four basic methods (bottom reflection, laser ranging by time difference, wave analysis, and thermal anomalies) can be used to provide information as to the location and depth of shallow water features. As in all detection problems, the final classification of a particular depth will depend on a "convergence of evidence" from several sensors, since each one by itself may not be wholly reliable.

Only the laser ranging sensor measures depth directly. Tradeoff studies show that presently available components and reasonable system sizes will provide laser systems that can measure depth to $\sim$45 m from an aircraft flying at a 460 m altitude over coastal waters with mean values of attenuation coefficients. However, spacecraft systems tend to be large, so that component and subsystem development must be carried out to assure that these systems are practical in size and reasonable in cost. Design studies show that, from

space, a laser system with state of the art components with a receiver collector area of at least 1.3 square kilometers could detect depths of .8 m in coastal waters with mean attenuation. Experimental verification of water-depth measurements with laser systems from aircraft should eventually be made in conjunction with testing of sensor techniques that utilize multispectral data or wave-refraction effects to measure depth.

A review of the multispectral methods of depth determination suggests that two or more channels might be used to compute absolute water depth provided that the values of water transmission and bottom reflection are known or can be assumed. The advantages of this approach are in the method of spectral filtering and in the immediate electrical output of the sensor. The use of a laser ranging system or other method of providing accurate measurements of depth at known points would serve as an effective method of calibrating the multispectral measurement for area coverage.

Under favorable observation conditions, wave analysis techniques making use of optical data processing may eventually achieve depth measurement with an accuracy of 10%. Observation of long wavelength swells, in the absence of local chop, and the use of optimum conditions of resolution and contrast in the imagery used for processing would all contribute to accurate determination of water depth.

4.12 SEA SURFACE TOPOGRAPHY

4.12.1 Introduction

The geocentric radius to the surface of the sea is a changing quantity at each point of the global oceans. Tidal forces, wind stress, and barometric pressure constantly remold the sea surface. These changes can be progressive, cyclic, or intermittent, but each has an explanation and significance in further understanding of physical processes at work within the oceans.

It has been suggested (39, 66) that global coverage of these effects might be provided by a very high resolution spaceborne altimeter system. The technique could be valuable for measurements of:

1) the patterns and transports of primary ocean currents;

2) tides, ocean-surface waves, and possibly tsunamis;

3) storm surges; and

4) eustatic changes of sea level.

Preliminary feasibility studies have been conducted. The usefulness of altimetry techniques for the above applications depends on the height resolution that could be achieved. A resolution of at least ± 1 meter would permit the detection of tides on the continental shelves, storm surges, and possibly the surface elevations associated with western boundary currents. A resolution of ± 0.1 m or less would greatly augment the scientific significance of all the other observations.

4.12.2 Sea Surface Slopes Relative to the Geoid

The measurement of the difference between the topography of the sea surface and the geoid is of fundamental importance to physical oceanography. Given the geopotential of the sea surface and knowing, from ship observations, the internal distribution of water density, we would then be able to compute the dynamic topography of all isobaric surfaces and the values of the global geostrophic transport of mass and heat by ocean currents at all depths. The great advantage in this approach is that oceanographic calculations of

geostrophic mass and heat transports by ocean currents could be made on the basis of facts, avoiding the traditional assumption that somewhere deep in the ocean the water is motionless.

The geoid is not known well enough to permit the calculation of all sea-surface slopes by differentiating the departure of the sea-surface from the geoid. The principal question is whether or not the larger slopes of the sea surface can be distinguished from the background of the geoid.

The largest surface slopes associated with ocean currents are found in the middle and high latitudes. The Gulf Stream, the Kuroshio, and in the Southern Hemisphere the Agulhas Current, are the strongest and most intense currents. Attempts to answer whether or not the slopes of the sea surface, referable to ocean currents, can be detected should start with areas dominated by strong western boundary currents, such as those mentioned above. Cross-stream slopes have been computed for the purpose of finding representative values for maximum slopes of the Gulf Stream and indicate that a height difference of about 140 to 150 cm can be expected in a traverse of 120 km across the Gulf Stream.

Measurements of sea slope in general and current boundaries in particular would be not only of basic scientific interest, but also of practical value. For example, the atmosphere overlies the world ocean and is nourished by oceanic vapor and heat. Detailed observation of the structure of the general oceanic circulation on a day-by-day basis would surely advance knowledge of the energy exchanges between the ocean and the lower atmosphere and improve capabilities to predict weather by numerical forecasting techniques.

For dynamical interpretation of calculations of mass transports, measurements of sea-surface relief would be most valuable if made with reference to the geoid, (that equipotential defined by the surface of a motionless ocean, under uniform atmospheric pressure, in which density is a function of pressure alone). There is now no method that permits the potential or gravity at the sea surface to be determined to high spatial resolution from satellite measurements.

The altimeter senses variations in the height of the ocean surface. To distinguish the ocean surface from the geoid, variations in the gravity field must also be sensed or known. In principle, this sensing can be done by continuous tracking of the satellite orbit variations. This technique should be adequate for averages over extents of 100 km or more. However, the satellite orbit tracking probably would not be accurate enough to pick up the variations of less than 100 km wavelength, which are appreciably damped at satellite altitude. However, it appears that surface gravity methods will become adequate over the next decade.

A difference of the slope inferred from the altimetry from that derived from the deflections of the vertical would indicate a slope of the sea surface with respect to the geoid, i. e., the presence of a current. The observed slope would be very close to the slope of an isobaric surface (1 atm) and with 0.1 m resolution in the altimetric data, yield a measurement of the dynamic slope accurate to 0.1 meter. Such resolution in the dynamic topography of an isobaric surface would permit the internal field of pressure and currents at all other depths in the ocean to be completed with an error of only 20% or so wherever measurements have been made of the vertical specific-volume gradient in the underlying water column.

While the western boundary currents, such as the Gulf Stream and Kuroshio, will provide sharply defined relief, altimetric changes over the broad Equatorial Current systems will be difficult to detect through the "noise" due to long waves, tides, and barometric pressure changes. For this reason, an altimeter should be accompanied by thermal, spectrophotometric, and possibly other ancillary sensors.

4.12.3 Tides

The use of a radar altimeter to study the tides should be concentrated on the theoretical problems of tides and not on the practical problems because, for most of the important parts of the world, present tidal predictions are more than adequate. For parts of the world where the tides are not well known, practical results can, of course, be obtained, but the geophysical global-scale problems are probably of greater interest.

To compute the work done by the moon and the Sun on the water of the sea (oceanic tidal dissipation) from the global field of sea level elevation, very precise observations (precision of $\pm 1/2^{\circ}$ in phase and ± 2 cm in amplitude) might allow detection of some significant tidal dissipation outside the ocean. In other cases, the U. S. Coast and Geodetic Survey has found that for purposes of tidal prediction at ports, 0.1-hourly values read with a precision of about 3 cm are sufficient. For various geophysical purposes (computing the ocean loading contribution to solid earth tides, computing the oceanic contribution to tidal fluctuations of the terrestrial magnetic field, etc.), knowledge of the deep-sea tidal elevation field to within 10% of its local value would be useful. These problems of enduring geophysical interest have been under study for centuries and satellite techniques now offer a means of solution.

4.12.4 Storm Surges

Storm surges are caused both by intense extratropical cyclones whose centers move near land masses. The strong onshore winds pile up water along the coast, and offshore winds push it away. Storm surge amplitudes can alter observed tidal levels by 3 or 4 m.

Theoretical surface elevation due to a storm surge at Barrow, Alaska have been computed (39). The effect of the surge extended along the coast from Cape Lisburne to Barrow, a distance of about 400 kilometers. At the peak of the storm, the surge exceeded 2 m over more than half of this distance. The surge exceeded 0.50 m for a distance out to sea of about 100 kilometers. The profile of such a surge could be measured in terms of 100-pulse averages every 8 km if a spacecraft were to pass over the area of interest during the time of the surge.

East coast hurricanes affect some portion of the coast from Florida to Maine for 2 or 3 days or longer. The chances are correspondingly high that one of the orbits of a polar orbiting spacecraft will pass over a region of interest where features of the hurricane surge can be measured. Similar statements hold for the east coast of Australia and for the Philippines, Taiwan, Japan, and the Kurile Islands.

Once it is proved practicable, a radar altimeter could become an important adjunct to the world weather watch as a way to provide valuable information on storm surges. However, because only elevations along the subsatellite track are measured, not all surges will be detected.

4.12.5 Tsunamis

Tsunamis are associated with seismic disturbances over the ocean floor usually in the vicinity of the deep trenches that border the Pacific Ocean. A tsunami is always caused by a seismic disturbance, but not all seismic distrubances cause tsunamis. A tsunami originating on the rim of the Pacific Ocean takes about a day to travel across the Pacific to the other side. Owing to the shape of the Earth, originally divergent waves can converge and increase in amplitude as they approach an antipodal point. The most prominent waves are present for the first day or so. If a satellite makes 14 orbits a day consisting of 14 north-bound and 14 south-bound passes, there is a high probability that 5 or more orbits will pass over a tsunami wave train as it progresses across the Pacific. But tsunamis are ephemeral. For this reason, it seems unlikely that an altimetric warning would precede tsunami detection by ground-based sensors (39). However, the open-ocean amplitude and progress of a tsunami wave train might best be determined by spacecraft altimetry. Such observations would also provide fresh information on the directional characteristics of each type of source.

Preliminary studies have shown that an altimeter with a per pulse rms error of 1 m or less would have the best chance of detecting a tsunami.

4.12.6 Radar/Laser Altimetry Studies

A series of studies have been performed on contract to SPOC and NASA (107, 108, 109) prerequisite to the building and testing of an altimeter system to measure the shape of the geoid or mean sea level from a spacecraft.

The altimeter performance requirements generated were for rms error in the range of 0.1 to 7 meters, and measurement densities ranging from 0.1 to 200 measurements per 10,000 km^2. A tradeoff analysis (108) compared the capabilities of candidate radar and laser altimeter systems to

meet these performance requirements. The study substantiated that satellite altimeter technology may be capable ultimately of providing better than 1 meter accuracy for useful geodetic data. Both radar and laser technologies offer promise of meeting ultimate required accuracy in tenths of meters, however, a radar altimeter system is better able to meet geodetic requirements than a laser altimeter system for the following reasons.

- Pointing Data - The radar altimeter system requires less accurate knowledge of attitude (pointing angle), than does laser system.
- Data Rate - The radar system measurement rate is ten times that of the laser system.
- Accuracy (Data Processing) - The radar altimeter system performs better spatial averaging of the sea surface, and better time averaging over a large number of ranging pulses.
- Volume - The radar system occupies less volume, than does the laser system.
- Weight - The radar altimeter system weighs significantly less than the laser altimeter system.

The GEOS-C mission will be the first satellite altimeter-flight. The GEOS-C altimeter is expected to measure altitude with an accuracy of 5 meters, precision of 5 meters and a resolution of 1 meter. The radar will probably operate at x band (8 to 10 GHz).

4.13 SUMMARY AND CONCLUSIONS

Under the auspices of SPOC, NASA, other government agencies, and private industry, extensive research has been conducted in the following areas: (1) analyzing data acquired from extant manned and unmanned satellites to determine oceanographic information content; (2) developing new instruments and techniques to acquire oceanographic data; (3) using off-the-shelf airborne instruments to acquire oceanographic data; and (4) the reduction and interpretation of acquired aircraft data for oceanographic purposes and studies aimed at ground truth comparisons. SPOC under its charter, has been especially active in sponsoring those activities concerned with developing new data acquisition techniques and analyzing data to determine its usefulness for better understanding ocean phenomena. NASA has been more active in conducting data acquisition programs, both aircraft and spacecraft, developing and building sensors, and studying means to transmit, compress and receive the acquired data.

Since the inception of SPOC in 1965, substantial progress has been made towards developing a capability to acquire ocean data and apply it to oceanographic problems using space and airborne remote sensors. This is a result of a concerted effort, not only by SPOC, but also by a wide range of other interests, both industrial and government. Research has covered: image enhancement techniques, selecting optimum frequencies and spectrums for acquiring data, comparison of sensor returns with surface truth data, developing new instrument techniques, evaluating data for information content, and many more. This research is prerequisite to achieving the capability to acquire ocean data remotely and now appears to be converging on that goal.

Some of the more significant achievements to date in oceanographic remote sensing which have been presented in this section are summarized below:

1. The successful detection of chlorophyll has been accomplished from low altitudes using spectroscopic methods.

2. Oil slicks have been successfully measured from aircraft altitudes using thermal IR imaging techniques. This technique shows the most potential for providing such information.

3. Nimbus HRIR data analyses have provided sea surface temperature (SST) information with fairly high resolution; however, it does not meet oceanographic requirements. Improved resolution and accuracy could be provided with a radiometer designed expressly for SST determination.

4. Preliminary research aimed at determining the feasibility of microwave techniques for obtaining sea surface temperature have been encouraging, but additional studies are required before the technique is fully developed.

5. Preliminary results of microwave tests to determine sea state indicate that sea surface emission can be correlated with wave heights for waves up to at least 6 meters in height.

6. Preliminary radar observations of ocean backscatter have shown an increase in off-vertical backscatter with increasing sea state. It has been demonstrated that wind speed is the dominant factor in determining the characteristics of the backscatter return.

7. Ocean currents have been identified using Nimbus HRIR and ATS TV data.

8. Significant positive results have been obtained employing a variety of remote sensing techniques for the detection of sea ice. Included are radar imagery and scatterometry, multispectral scanning, laser profiling, IR radiometry and microwave imaging.

9. The use of a specially designed IR radiometer for determining heat flow from the sea surface appears to be limited to low altitude aircraft flights because of atmospheric interference. The use of microwave techniques for heat flow determination requires a significant increase in state of the art.

10. Water depths up to 45 m have been obtained using spacecraft color photography. Pulse laser systems flown in aircraft have also shown a significant potential for determining water depth in shallow areas up to ~100 meters in depth.

SECTION 5

STATUS OF REMOTE SENSING OF OCEANOGRAPHIC PARAMETERS

The current status of remote sensing techniques for ocean applications is detailed in two sets of tables: Tables 5.1 - Status of Remote Sensor Development, and Tables 5.2 - A Discussion of the Status of Remote Sensor Development. Information presented in these tables was acquired from various recent sources of information. They are, in order of importance, personal interviews with scientists and engineers working in the remote sensing field, mailed inquiries returned by scientists and engineers, and reports describing recent results and progress in remote sensing. This latter group included both SPOC funded studies as well as those funded by other agencies.

Fifty-nine questionnaires were distributed to industry, university and government organizations engaged in remote sensor R&D activities (see Appendix I). Twenty-eight were returned for a response rate of 47 percent. This group of questionnaires provided not only the highest rate of return but also the most informative returns. Eight personal interviews were also conducted with individuals active in the areas of sensor development.

Information in the tables indicates that it is feasible to build a number of desired instruments using current state of the art techniques and fly them in space to provide useful data for oceanography. This, of course, does not mean to imply that all potential applications for each instrument could be satisfied with state of the art capability; they cannot, as is also evident in the tables. Naturally, most of the data obtained initially from satellite systems would be of an experimental nature. It should be noted also that a much larger number of sensors are operational in an aircraft mode and are presently capable of providing data of use for a wider range of applications than is the case with satellite sensors. This is to be expected since the lower altitudes simplify instrument requirements for high resolution data. Also there are few weight or power restrictions, no communication problems, and sensor reliability and lifetime are not as critical.

and if possible, obtain data of geodetic and Earth physics interest. The data from this flight should be of great importance in the further radar altimeter development required to obtain the 10 cm accuracy needed for important oceanographic applications.

A conclusion to be made regarding a number of sensors is that sensor development is more advanced than the ability to accurately determine the meaning of the data and how it relates to the ocean parameter under observation. This conclusion was arrived at after studying Tables 2.1 and 2.2, reviewing results of recent investigations, and discussing the situation with personnel intimately associated with remote sensing feasibility studies.

This is especially true in the case of microwave sensors (including radar) for determining sea state (see Sections 4.5.2 and 4.5.3) and surface temperature (see Section 4.4.3.3)and also for spectrometry techniques for determining the meaning of certain spectral signatures (see Section 4.2). This is not meant to imply that there are no development problems associated with the instruments themselves; there are, but they appear to be less complicated, i.e., microwave antenna design, than some data interpretation problems where a number of variables, some unknown, are involved.

Another problem area that impacts on data reduction and limits the overall effectiveness of infrared and optical technology for surface studies is the inherent attenuation within of the visible and IR spectrum caused by the atmosphere. Several studies have been undertaken in this area (28, 53, 145), however, many unknowns still exist. This attenuation must be better understood so that it can be recognized in the data and subsequently accounted for. A third area where additional research is required is the determination of the optimum spectral regions for surveying ocean color, see Section 4.10. Several studies have been conducted in this area (113, 141, 163), but there is still not full agreement on those spectral regions that will provide the greatest amount of information for ocean studies.

The significance of the above statements is that at present the further development of remote sensing instruments for use aboard satellites is in many cases constrained by a lack of information on which to base further develop-

ment. This need for additional information was expressed by a majority of instrument designers. Without comparisons of the results of existing aircraft and spacecraft instrument measurements with surface truth and analysis of the causes of any differences it is not possible for the sensor designer to identify wherein his instrument must be modified to meet requirements. This need for correlation of existing data with surface truth is the most important information needed to support additional instrument development. Another information requirement for instrument designers is a clear statement of data needs, e.g., what part of the visible spectrum needs to be sensed, what is the maximum required repetition rate, etc. Until the cognizant instrument designers receive the information input which they require, little additional advance in instrumentation will be made in many areas.

TABLE 5.1-1

STATUS OF REMOTE SENSOR DEVELOPMENT TO MEASURE OCEANOGRAPHIC PHENOMENA/PARAMETERS

PHENOMENON: MARINE ORGANISMS

PARAMETERS	RESOLUTION	SENSOR STATUS: OFF THE SHELF	PROTOTYPE OPERATIONAL	FINAL DESIGN COMPLETED	PRELIMINARY DESIGN COMPLETED	FEASIBILITY STUDIES UNDERWAY	FEASIBILITY STUDIES TO BE INITIATED	SENSOR OR TECHNIQUE	COMMENT
SURFACE FISH SCHOOLS	10-20 m (spatial)	A			S			Photography	
						X		Multispectral photography	
SUB-SURFACE FISH SCHOOLS	10-20 m (spatial)					X		Multispectral photography	Depth sounding system is expected to have an accuracy of ± .5 m or 5% of measured depth.
	±1 m (vertical)		X					Pulsed-light Airborne Depth Sounding Technique	
FISH OIL						X		IR Radiometry	
						X		Spectrometry	
PLANT LIFE			A		S			Spectrophotometry	TRW's Spectrophotometer (WISP) has been tested by a number of marine biologists in a variety of geographical areas. Results are encouraging.
CHLOROPHYLL	$\pm 0.1 mg/m^3$		A		S			Multispectral Scanning/Photography	

NOTE:

A = Instruments developed for operation from Aircraft

S = Instruments developed for operation from Spacecraft

X = Instruments being developed for operation on either Aircraft or Spacecraft or both

(Continued)

TABLE 5.1-1 (Cont'd.)

STATUS OF REMOTE SENSOR DEVELOPMENT TO MEASURE OCEANOGRAPHIC PHENOMENA/PARAMETERS

PHENOMENON: MARINE ORGANISMS

PARAMETERS	RESOLUTION	SENSOR STATUS: OFF THE SHELF	PROTOTYPE OPERATIONAL	FINAL DESIGN COMPLETED	PRELIMINARY DESIGN COMPLETED	FEASIBILITY STUDIES UNDERWAY	FEASIBILITY STUDIES TO BE INITIATED	SENSOR OR TECHNIQUE	COMMENT
BIOLUMINESCENCE		A			S			Photography	
			A			S		Low level light sensors	
SEA WEED	10-20 m (spatial)	A			S			Radar Imagery	
		A			S			Multispectral Photography	
FLUORESCENCE			A					Fraunhofer Line Discriminator	Potential applications include sensing fish oils and other fluorescent pollutants.
SALINITY SURFACE	10 PPM (Accuracy)					X		Microwave Radiometry	The microwave radiometer portrays greatest sensitivity for salinity at a frequency of 1.0 GHz. It appears that such a device may be able to measure salinity along coastal and estuary regions where great variances in salinity exist due to influences of river outflow and runoff of precipitation.
SUBSURFACE*									
SEA SURFACE TEMPERATURE (See Table 5.1-3)									

*In situ sensor required.

TABLE 5.1-2

STATUS OF REMOTE SENSOR DEVELOPMENT TO MEASURE OCEANOGRAPHIC PHENOMENA/PARAMETERS

PHENOMENON: POLLUTION

PARAMETERS	RESOLUTION	SENSOR STATUS: OFF THE SHELF	PROTOTYPE OPERATIONAL	FINAL DESIGN COMPLETED	PRELIMINARY DESIGN COMPLETED	FEASIBILITY STUDIES UNDERWAY	FEASIBILITY STUDIES TO BE INITIATED	SENSOR OR TECHNIQUE	COMMENT
PARTICULATE	>60 m (spatial)	A			S			Photography	The detection of pollution requires relatively high resolution sensors. The resolution's required (from space) are state-of-the-art for photography only.
			A			S		IR Radiometry	The use of spectrometer techniques to detect oil (Baird Atomic and Barringer Res.) has not progressed past the Lab. phase. Feasibility from aircraft and spacecraft has yet to be determined.
CHEMICAL (in solution)	.01μ (spectral)		A			S		Spectrophotometry	Other pertinent parameters that may provide information include color, surface, temperature, and chlorophyll.
						X		Baird Atomic's Active Sensing System	
OIL	1.0°C (Temperature)		A		S			Multispectral Scanning	
THERMAL			A		S			Multispectral Photography	
								Microwave Radiometry	

TABLE 5.1-3

STATUS OF REMOTE SENSOR DEVELOPMENT TO MEASURE OCEANOGRAPHIC PHENOMENA/PARAMETERS

PHENOMENON: WATER TEMPERATURE

PARAMETERS	RESOLUTION	SENSOR STATUS: OFF THE SHELF	PROTOTYPE OPERATIONAL	FINAL DESIGN COMPLETED	PRELIMINARY DESIGN COMPLETED	FEASIBILITY STUDIES UNDERWAY	FEASIBILITY STUDIES TO BE INITIATED	SENSOR OR TECHNIQUE	COMMENT
TEMPERATURE SURFACE	$3^{\circ}C$	S						IR Radiometry	Spatial resolutions of 10 km^2 near islands, coasts, and current boundaries, and 500 km^2 in the open ocean appears adequate for most applications.
			A			X		Microwave Radiometry	
		A						Airborne Radiation Thermometry	
	$1^{\circ}C$	A;S*			S			IR Radiometry	State-of-the-art is available to build IR radiometer to meet oceanographic requirements, $1.0^{\circ}C$. Variations are now spaceborne in NIMBUS 4, ITOS. More studies are needed of atmospheric attenuation of signal.
						X		Microwave Radiometry	Extensive development needed to use microwave radiometer from aircraft or spacecraft to acquire accurate temperature data. Basically it is a low resolution instrument.
		A						Airborne Radiation Thermometry	
(Cont'd)									

* ITOS scanning radiometer may possibly provide $1^{\circ}C$ resolution.

TABLE 5.1-3 (Cont'd.)

STATUS OF REMOTE SENSOR DEVELOPMENT TO MEASURE OCEANOGRAPHIC PHENOMENA/PARAMETERS

PHENOMENON: WATER TEMPERATURE

PARAMETERS	RESO-LUTION	SENSOR STATUS: OFF THE SHELF	PROTOTYPE OPERATIONAL	FINAL DESIGN COMPLETED	PRELIMINARY DESIGN COMPLETED	FEASIBILITY STUDIES UNDERWAY	FEASIBILITY STUDIES TO BE INITIATED	SENSOR OR TECHNIQUE	COMMENT
	0.1°C					X		IR Radiometry	Field accuracy of the ART with correction = 0.4°C.
						X		Microwave Radiometry	
		A				X		Airborne Radiation Themometry	
SUBSURFACE*									
HEAT FLOW	0.01°C		A			X		IR Radiometry	The IR Technique for determining heat flow is not feasible from space and microwave radiometry state of the art is not currently available.
						X		Microwave Radiometry	

* In situ sensors required.

TABLE 5.1-4

STATUS OF REMOTE SENSOR DEVELOPMENT TO MEASURE OCEANOGRAPHIC PHENOMENA/PARAMETERS

PHENOMENON: SEA STATE

PARAMETERS	RESO-LUTION	SENSOR STATUS: OFF THE SHELF	PROTOTYPE OPERATIONAL	FINAL DESIGN COMPLETED	PRELIMINARY DESIGN COMPLETED	FEASIBILITY STUDIES UNDERWAY	FEASIBILITY STUDIES TO BE INITIATED	SENSOR OR TECHNIQUE	COMMENT
WAVE HEIGHT	~1 m		A			X		Radar Scatterometry	The use of radar techniques to determine sea state are under investigation. Sea state cannot be characterized by a single parameter. The higher frequency waves are expected to be closely related to local surface winds and apparently are the part of the spectrum sensed by the scatterometer.
WAVE LENGTH	~30 m to >300 m		A		X			Radar Imagery	
			A			X		Microwave Radiometry	
		A			X			Photography	
			A			X		Laser Altimetry	
			A		X			Radar Altimetry	
WAVE DIRECTION	5°		A		X			Photography	A laser profilometer built and tested by A. P. L. and mounted in an aircraft flying at 60 meters altitude delineated ripples of 2.5 cm or less and waves of any height.

TABLE 5.1-5

STATUS OF REMOTE SENSOR DEVELOPMENT TO MEASURE OCEANOGRAPHIC PHENOMENA/PARAMETERS

PHENOMENON: OCEAN CURRENTS

PARAMETERS	RESOLUTION	SENSOR STATUS: OFF THE SHELF	PROTOTYPE OPERATIONAL	FINAL DESIGN COMPLETED	PRELIMINARY DESIGN COMPLETED	FEASIBILITY STUDIES UNDERWAY	FEASIBILITY STUDIES TO BE INITIATED	SENSOR OR TECHNIQUE	COMMENT
CURRENTS HORIZONTAL/ VERTICAL	100-1000 m (spatial)	A			S			Color Photography	Large ocean currents have been detected from space with Nimbus HRIR data. Resolution needs to be improved to meet oceanographic requirements.
			A		X			Spectrophotometry	
DIRECTION	5°	A			X			IR Radiometry	
			A		S			Multispectral Scanning	
			A		X			Multispectral photography	
		A						Airborne Radiation Thermometry	
TEMPERATURE	1° C	A			X			IR Radiometry	
VELOCITY*	1-4 knots		A			X		Microwave Radiometry	

* In situ sensor required.

TABLE 5.1-6

STATUS OF REMOTE SENSOR DEVELOPMENT TO MEASURE OCEANOGRAPHIC PHENOMENA/PARAMETERS

PHENOMENON: ICE

PARAMETERS	RESOLUTION	SENSOR STATUS: OFF THE SHELF	PROTOTYPE OPERATIONAL	FINAL DESIGN COMPLETED	PRELIMINARY DESIGN COMPLETED	FEASIBILITY STUDIES UNDERWAY	FEASIBILITY STUDIES TO BE INITIATED	SENSOR OR TECHNIQUE	COMMENT
SEA ICE	10-100 m	A			S			Photography	Sea ice extent and movement have been measured from space using TIROS TV and Nimbus HRIR data.
EXTENT	(spatial)	A			S			Television	However, improved resolution is required for operational purposes.
MOVEMENT	1.0-2.0°C		A			X		Radar Imagery	
			A			X		Microwave Radiometry	
THICKNESS*			A			X		IR Radiometry	IR data is influenced by a number of extemporaneous parameters, thus does not appear promising for Arctic areas which are frequently cloud covered.
COMPOSITION*			A			X		Multispectral Photography	
			A			X		Multispectral Scanning	
ICEBERGS	(10-20 m)	A			S			Photography	The ability to locate and track icebergs (all weather) of ≈10 m size via space acquired data would be of great value to the International Ice Patrol.
SIZE	(spatial)		A			X		Radar Imagery	
VELOCITY			A			X		Microwave Radiometry	
DIRECTION						X		Multispectral Photography	

* In situ sensor required.

TABLE 5.1-7

STATUS OF REMOTE SENSOR DEVELOPMENT TO MEASURE OCEANOGRAPHIC PHENOMENA/PARAMETERS

PHENOMENON: OCEAN COLOR

PARAMETERS	RESOLUTION	SENSOR STATUS: OFF THE SHELF	PROTOTYPE OPERATIONAL	FINAL DESIGN COMPLETED	PRELIMINARY DESIGN COMPLETED	FEASIBILITY STUDIES UNDERWAY	FEASIBILITY STUDIES TO BE INITIATED	SENSOR OR TECHNIQUE	COMMENT
COLOR	30-1,000 meters (spatial)	A			S			Photography	Apollo/Gemini color photography (Hasselblad Camera) produced excellent photographs with ≈100 m. resolution.
			A			S		Spectrophotometry	Wavelength spectra of interest are: .4 to .58 μ; .46 to .51 μ; .51 to .56μ
	.04μ (spectral)		A		S			Multispectral Scanning	Optimum spectrum has yet to be determined.
			A			S		Multispectral Photography	Information on ocean water color is useful for many applications, such as the determination of: pollution, chlorophyll, currents, water depth, bottom characteristics, and so forth.

TABLE 5.1-8

STATUS OF REMOTE SENSOR DEVELOPMENT TO MEASURE OCEANOGRAPHIC PHENOMENA/PARAMETERS

PHENOMENON: BATHYMETRY

PARAMETERS	RESO-LUTION	SENSOR STATUS: OFF THE SHELF	PROTOTYPE OPERATIONAL	FINAL DESIGN COMPLETED	PRELIMINARY DESIGN COMPLETED	FEASIBILITY STUDIES UNDERWAY	FEASIBILITY STUDIES TO BE INITIATED	SENSOR OR TECHNIQUE	COMMENT
BATHYMETRY	0.1-2m	A			S			Color Photography	Water depth determination appears feasible over a depth range of 0-90 meters. Using remote sensing techniques it is felt that the depth of about 50% of the world's coastal waters are amenable to airborne survey by laser fathometer to at least 20 m depth, about 35% to airborne laser bathymetry to over 40 m and to aerial photography to over 20 m depth, and about 10% to airborne laser survey to over 60 m depth and to airphotography to over 30 m depth. Fifteen percent are not amenable to optical methods at all. Data manipulation techniques for color photography and other type images, such as image enhancement may prove valuable in increasing information content.
			A		S			Multispectral Photography	
			A		S			Multispectral Scanning	
			A			X		Laser Depth Ranging	
			A		X			Spectrophotometry	
			A			X		IR Radiometry	

TABLE 5.1-9

STATUS OF REMOTE SENSOR DEVELOPMENT TO MEASURE OCEANOGRAPHIC PHENOMENA/PARAMETERS

PHENOMENON: TIDES

PARAMETERS	RESOLUTION	OFF THE SHELF	PROTOTYPE OPERATIONAL	FINAL DESIGN COMPLETED	PRELIMINARY DESIGN COMPLETED	FEASIBILITY STUDIES UNDERWAY	FEASIBILITY STUDIES TO BE INITIATED	SENSOR OR TECHNIQUE	COMMENT
DEEP OCEAN	<0.3 m (height)					X		Radar Altimetry	The measurement of tides on a global scale is quite feasible as tidal ranges of several meters are frequent over areas where pulse averaging can reduce errors to ±0.3 meters and less. The use of a radar altimeter to study the tides should probably be concentrated on the theoretical problems and not on the practical problems as, for most of the important ports of the world, tidal predictions are more than adequate. One of the more applicable techniques of analysis involves the computation of the tidal potential and the use of a Kernal function to derive the form of the profiles (Munk and Cartwright 1966).
HEIGHT						X		Laser Altimetry	
PERIOD									
CONTINENTAL SHELF	<0.3 m (height)					X		Radar Altimetry	
						X		Laser Altimetry	
HEIGHT									
PERIOD									

TABLE 5.1-10

STATUS OF REMOTE SENSOR DEVELOPMENT TO MEASURE OCEANOGRAPHIC PHENOMENA/PARAMETERS

PHENOMENON: STORM SURGES; TSUNAMIS

PARAMETERS	RESOLUTION	SENSOR STATUS: OFF THE SHELF	PROTOTYPE OPERATIONAL	FINAL DESIGN COMPLETED	PRELIMINARY DESIGN COMPLETED	FEASIBILITY STUDIES UNDERWAY	FEASIBILITY STUDIES TO BE INITIATED	SENSOR OR TECHNIQUE	COMMENT
DIAMETER	1-2 m (vert.)					X		Radar Altimetry	Storm surges may range up to 7m in height.
HEIGHT						X		Laser Altimetry	Studies have shown the feasibility of these techniques for storm surge detection; however, extensive development is required to bring them to fruition.
						X		Radar Scatterometery	The laser altimeter is vulnerable to atmospheric influences and is completely inoperative in the presence of clouds. The radar is less affected by atmospheric transmission but sea spray and heavy precipitation present accuracy problems.
DIRECTION*									
VELOCITY*									If systems to detect sea level and slope are perfected they may also be able to detect tsunamis, however, since they are transient phenomena, the probability that an orbiting spacecraft could detect them is relatively low.

*In situ sensor required.

TABLE 5.1-11

STATUS OF REMOTE SENSOR DEVELOPMENT TO MEASURE OCEANOGRAPHIC PHENOMENA/PARAMETERS

PHENOMENON: GEOID

PARAMETERS	RESOLUTION	SENSOR STATUS: OFF THE SHELF	PROTOTYPE OPERATIONAL	FINAL DESIGN COMPLETED	PRELIMINARY DESIGN COMPLETED	FEASIBILITY STUDIES UNDERWAY	FEASIBILITY STUDIES TO BE INITIATED	SENSOR OR TECHNIQUE	COMMENT
SEA SLOPE	± 10 cm					X		Radar Altimetry	Requirements are set forth in the Williams College Summer Study Report. State of the art is believed to be feasible within the 1970's time period, but extensive development is required. Using laser techniques for these measurements requires a device to discriminate between clouds and the ocean surface.
SEA LEVEL	± 10 cm					X		Laser Altimetry	
SEA SURFACE GEOMETRY	± 10 cm					X		Gravity Gradiometry	

TABLE 5.2-1
STATUS OF REMOTE SENSOR DEVELOPMENT
- DISCUSSION -

Instrument Description	Applicable Parameters	Instrument Availability	Potential for Meeting User Requirements	Comments
Camera (Multispectral) Variety of aircraft multispectral camera systems are available and many could be adapted for space use.	Ocean Color • Water Depth • Sea State (glitter and non-glitter patterns) • Currents • Pollution • Coastal Phenomena	A variety of airborne multispectral cameras are available and have been flown on an operational basis. A number of systems have been proposed for space flight and could be built with current state of the art. A camera system is scheduled for SKYLAB. A multispectral camera system consisting of 4 Hasselblad cameras was flown on Apollo 9. NASA has various camera systems installed in its P3A, C130 and RB57.	Most oceanographic requirements call for repetitive coverage over a wide geographical area which, if cameras were used, would require extensive film return mechanisms or the use of bi-mat process. Both limit the usefulness for an operational system unless it is manned or man attended. If these limitations can be overcome many users still prefer photographs especially over coastal phenomena. For aircraft systems it provides high resolution coverage, and has wide application.	The determination of the optimum spectrums have yet to be agreed to. The accurate processing of color film to obtain identical calibration standards from one processing run to the next is difficult and time consuming. It is difficult to automatically process, reduce and interpret photographs. However, there is extensive information in a picture and people are used to handling photos. Image enhancement techniques are being studied to determine their contribution to obtain additional information.
Television • 2 Inch Return Beam Vidicon Spectral range .475 - .575μ .580 - .680μ .690 - .830μ ~60 m resolution • Silicon Vidicon + silicon intensifier target sensor Spectral range .2 to 1.1μ Resolution ~2 m from ~180 km (40" F.L.) • Low Level Light TV	Sea Ice (extent) Ocean Color Currents Water Depth	RCA's RBV system is scheduled for ERTS A and B (1972 launch). TV cameras using silicon vidicon and silicon intensifier target sensor are presently under construction and planned for SKYLAB. A prototype has been tested. Low level light TV systems are operational for aircraft use.	Resolution capability of the RBV will be a significant improvement over AVCS (TIROS, ESSA, TOS). System should provide excellent data for determining sea ice extent, except when cloud covered. Depending on the RBV's ability to accurately measure color, the instrument may provide information on ocean color of value for detecting ocean currents, water depth, etc. Low level light TV has been used to determine applicability for locating fish schools by detecting associated bioluminescence.	Extensive experience and facilities exist for handling TV data. However, it appears that certain rectification problems will exist with RBV data.

TABLE 5.2-2
STATUS OF REMOTE SENSOR DEVELOPMENT
- DISCUSSION -

Instrument Description	Applicable Parameters	Instrument Availability	Potential for Meeting User Requirements	Comments
Laser System • Continuous Wave Helium-Neon Laser 6328Å	Ocean Surface Profiling (Sea State) Sea Ice	A number of prototypes have been built and tested in aircraft up to altitudes of 9,000 meters. The applicability to space has not been determined, but preliminary theoretical results are promising.	This technique holds significant potential for obtaining profiles of ocean waves. Low altitude flights ~150 m have delineated wave heights to an accuracy of ~.06 m. For operations from space, cloud attenuation of signal would reduce usefulness. Laser system together with radar/microwave system could prove to be optimum system.	Further testing under varying atmospheric conditions is required. Laser profile reveals directly topography of the ice, consequently ice age can be made after studying profile character. At present, an airborne system could support statistical ice data collection.
• Pulse 1) Yttrium Aluminum Garnet Laser(YAG) 2) Neon Laser (5401 Å)	Depth Determination (Bathymetric Surveys) Water Turbidity	Pulse laser systems for operation from aircraft are still in the prototype stage, with a number of systems being tested. Results are encouraging. Most testing has been by the Navy or on contract to the Navy.	The potential for meeting user requirements is great, especially for airborne systems. Tests have provided .5 m accuracy in shallow murky water. Theoretical studies have shown depth determination up to 93 meters under ideal conditions is feasible.	Spacecraft systems would tend to be large, so component and subsystem development must be carried out to assure systems are practical
Multispectral Scanner • ERTS A& B System .5 to 1.1μ (4 bands) • ERTS B .5 to 1.1μ (4 bands) 10.4 to 12.6μ (1 band) • Resolutions ~ 65 meters 200 m (IR band) • Optical Mechanical Scanner (Michigan) 16 channels, 0.32 to 2.6μ 2 channels, 4.5 to 13.5μ	Ocean Currents Chemical Pollution Shoal Detection Sea Surface Temperature Sea Ice	Two different scanner systems are planned for ERTS A& B, one for each flight. A scanner is also planned for SKYLAB. Other scanner type instruments have been flown previously in space, for example, Image Disector Camera System, as well as various IR scanners on meteorological satellites. A number of prototype systems have and are being flown in aircraft. For example, the University of Michigan scanner has been used extensively for ocean studies. Other scanners have been built by Hycon, Hughes, Bendix, ITT, and others.	Scanners appear to hold great potential for providing useful data. For example, they provide imagery and radiometric measurements in several spectral bands. Operational systems will require only a few channels, present systems with many channels are for test purposes only, to determine most suitable channels for various applications.	Extensive data reduction studies have been conducted. Pattern recognition techniques show significant promise. Areas requiring additional work to achieve an operational capability include hybrid data processor for spectral pattern recognition, and on-board data processing for bandwidth reduction. The more channels the more data requires transmission Data analysis studies are also continuing to determine exactly how the data relates to various ocean phenomena.

TABLE 5.2-3
STATUS OF REMOTE SENSOR DEVELOPMENT
- DISCUSSION -

Instrument Description	Applicable Parameters	Instrument Availability	Potential for Meeting User Requirements	Comments
Spectrophotometer Resolution: 2.3 m. from 18.3 km * 30.5 m from 18.3 km * 100 Å spectral band-width, 30 spectral bands - .4 to .7μ * 2 modes of operation	Spectral Reflectance (Ocean Color) Chlorophyll Pollution Bathymetry	TRW has built a prototype instrument and tested it from low altitude aircraft. Results are encouraging. Spectrophotometer will be built for flight test in NASA's RB57 (high altitude test).	The instrument has the potential to detect chlorophyll to an accuracy required for location of environment suitable for fish. Ocean color is a fundamental measurement parameter. Using a spectral measurement technique allows signatures to be broken up into relatively narrow wave-bands allowing minute differences to be detected.	Data handling is more or less state of the art; however, additional development is required to achieve operational status. Development of improved algorithms for data interpretation is needed. More data acquisition with simultaneous ground truth is required.
Spectrometer Visible and IR spectrum (~0.4 - 13 μ)	Spectral Reflectance • Ocean Color • Chlorophyll • Fish Type • Pollution	Spectrometers applicable to ocean studies are flying in a number of aircraft including: NASA RB57 (IR) NASA P3A (IR) TRW (visible)	These instruments in A/C tests show a significant potential for detecting chlorophyll concentrations, fish species, pollution types; the extrapolation to space altitudes has been shown, however, feasibility studies are still required.	The determination of unique signatures for various fish species is still under study. Some have been determined. Techniques need additional tests with schooling fish on the open ocean.
Airborne* Infrared Radiometer Specifications may vary between instruments General specifications are •Spectrum-10.5 - 12.5μ or 8.0 - 13.0μ •Temp. resolution ~±0.3°C •Temp. range -2° to +35°. *See Table 5.2-4 for spacecraft systems	•Sea Surface Temp. -Currents -Fish •Surface Oil •Sea Ice •Sea/Air Interaction	The Airborne Radiation Thermometer (ART) is an off the shelf item and is currently installed in a number of aircraft (USCG, ASWEPS, NAVOCEANO, etc.). A number of other airborne radiometers have been built to individual specifications and are installed in various aircraft, both research and operational. The following companies are some of those active in the field Barnes Engr. Co. Bendix Aerospace Corp. Block Engr. Co. Ramsey Engr. Co. Santa Barbara Res. Corp. (Hughes)	At present IR radiometric techniques are the only temperature measuring systems operational, (A/C and S/C). The state of the art appears to be available for acquiring data to meet most user requirements, (1°C) for sea surface temperature. Clouds are a limiting factor. This technique is not all-weather.	Because of low altitude that these instruments are flown, atmosphere influences are minimal but they do influence data and must be compensated for. Additional studies are required in this area. Many studies have been accomplished relating air-borne acquired surface temperature to detection of currents, oil pollution, and others. Thus meaning of data and how it relates to ocean phenomena is understood to a large degree with additional studies continuing.

TABLE 5.2-4
STATUS OF REMOTE SENSOR DEVELOPMENT
- DISCUSSION -

Instrument Description	Applicable Parameters	Instrument Availability	Potential for Meeting User Requirements	Comments
Spaceborne IR Radiometer • MRIR - Nimbus • HRIR - Nimbus 9 km resolution $\pm 1^{\circ}$ - $2^{\circ}C$ temp. res. • SR-ITOS 7.5 km resolution 1 - $4^{\circ}C$ temp. res. Spectrum - 0.5 - 12.5u	Sea Surface Temperature • Currents • Pollution • Sea/Air Interaction	Operational - primarily meteorological instruments.- additional launches of ITOS's with similar instruments are expected on a regular basis. Additional Nimbus Satellites will also be launched with IR radiometer, part of complement. Data is available to interested researchers.	State of the art is available to meet user requirements from space. Those instruments currently spaceborne do not provide resolution required for most oceanographic applications. SR is more appropriate for ocean studies since it has 10.5 - 12.0μ band (not affected by reflecting sunlight.	More studies required of atmospheric attenuation of signal, so data can be corrected. Cloud detection device should accompany radiometer for cloud discrimination.
Microwave Radiometer • NASA P3A - Multifrequency Radiometer • NASA Convair 990 - 1.55 cm imager 3.2 cm radiometer	1. Sea Surface Temperature 2. Sea State 3. Sea Ice 4. Surface Mineral Oil 5. Salinity	State of the art is more or less available to build a specific instrument if final specifications could be determined, i.e., frequency, antenna systems, polarization, etc. Antenna design is one of the weak areas. The first instrument for space flight is scheduled for Nimbus E (meteorological applications). A radiometer is also to be flown on SKYLAB. Specifications call for a resolution of ~2.0° K over 50-400°K range. A variety of prototype models have been test flown in aircraft. The following companies are some of those that are active in the field: Aerojet General Corp. Ryan Aeronautical Corp. Microwave Systems, Inc. Westinghouse Corp. General Electric Corp. RCA Corp.	1. Feasibility remains to be determined, as variations in emissivity such as surface roughness related to sea state tend to mask thermal change. 2. By proper choice of sensor characteristics (wavelength, polarization, and viewing angle), it may be possible to distinguish between emission associated with small and large scale surface roughness. 3. The difference in brightness temperature between ice and water is very large, even though both may be at nearly the same physical temperature. Determination of ice thickness may also be feasible. 4. May offer a means of detecting oil and measuring its thickness if the various parameters affecting microwave return can be distinguished, i.e., oil incidence angle, wind speed, etc. 5. May prove feasible for determining salinity along certain coastal areas.	Further study required of influences of foam, winds emissivity, precipitation, clouds, etc. It is felt that the state of the art of building the instrument is significantly ahead of data interpretation capabilities. Extensive ground truth information simultaneous with over flight is necessary to improve data interpretation.

TABLE 5.2-5
STATUS OF REMOTE SENSOR DEVELOPMENT
- DISCUSSION -

Instrument Description	Applicable Parameters	Instrument Availability	Potential for Meeting User Requirements	Comments
Radar Scatterometer (Measures the radar reflection coefficient as a function of incidence angle.)	Sea State (Wind) Sea Ice Conditions	Prototype instruments are installed in NASA's and NRL's test aircraft. NASA's Aircraft has 1) 400 MHz scatterometer 2) 1.6 GHz scatterometer 3) 13.3 GHz dual polarized scatterometer NRL's Aircraft has a 4 frequency radar system: 8910 MHz, 4455 MHz, 1228 MHz, and 428 MHz.	Present observations indicate an increase in off-vertical radar backscatter with increasing wind speed which in turn relates to wave height, wind direction also has a significant affect on data. At the present time this technique appears to hold the most potential for providing all weather sea state information.	Extensive studies are required before this technique can be used on an operational scale. Experimental error is sufficient that the absolute level of the scattering coefficient versus angle curve must be established by better experiments. The results of experiments using the NASA radar are not compatible with NRL results, and must be resolved. Thus proper choice of frequency has yet to be determined.
Radar Imager • 16.5 GHz SLR (converted Philco DPD-2 System) Synthetic aperture receives and transmits horizontal and vertical polarized waves. • Four Frequency Radar System (NRL)* X Band 8910 MHz C Band 4455 MHz L Band 1228 MHz P Band 428 MHz	Sea Ice Coastal Processes Icebergs Sea Surface Roughness*	NASA has two SLR systems installed in its aircraft (P3A, C130) Previously AN/APQ 96 and AN/APQ 56 systems as well as others were used to acquire data. At the present time no SLR's are proposed or planned for spaceflight. State of the art is more or less available for building and flying a SLR system in space. Constraints are weight, volume, and power. These systems have not been designed specifically for acquiring this type of data, thus they are not optimum. Cost and classification are major factors.	The capability of radar systems to provide useful data under weather and lighting conditions unsuitable for visible sensors is significant. Excellent surface resoluting is obtained with SLR, thus its application for sea ice, icebergs and coastal phenomena is dictated. With sophisticated techniques being incorporated in new SLR's sea surface roughness may also be determined.	The radar imaging system's output is in an image format analagous to a photograph, thus photo interpretation techniques are applicable as well as computerized image enhancement techniques.

* Described under radar scatterometer system

TABLE 5.2-6
STATUS OF REMOTE SENSOR DEVELOPMENT
- DISCUSSION -

Instrument Description	Applicable Parameters	Instrument Availability	Potential for Meeting User Requirements	Comments
Radar Altimeter • GEOS-C Noncoherent pulse tracking system, digital signal processing. Approx. RF = 10 GHz, 10 MHz bandwidth	Mean Sea Level Currents Storm Surges Tides, Waves, Tsunamis	GEOS-C hardware has not been built, although the design will be based on proven techniques and hardware. Other altimeters have been flight tested on aircraft; NASA has an APN-159 radar altimeter installed on its P3A. A radar system appears more applicable for meeting user requirements than does a laser altimeter, because: • Radar requires less accurate knowledge of attitude than does laser. • Radar measurement rate is 10 times that of the laser. • Radar performs better spatial averaging of the sea surface.	The GEOS-C altimeter will provide an accuracy of approximately 5 m, hence, its use for ocean studies per se will be extremely limited. If a resolution of 1 m eventually achieved the detection of tides on the Con Shelf, storm surges, and possibly surface elevations associated with western boundary currents can be achieved. A resolution of 0 1 m would greatly augment the scientific significance of the above, but will not be obtained in the first generation space systems.	Additional research needs to be conducted to determine variations of return pulse shape as a function of pulse width, altitude, sea state, and size of illuminated area. Improved signal processing techniques and sensor calibration techniques must be developed. Extensive and accurate ground truth data is a must with both aircraft and spacecraft tests.
Fraunhofer Line Discriminator Spectrum: Sodium D_2 Fraunhofer line (5890 Å) Resolution: 26 m from 1500 m altitude	Fluorescence Coefficient of Water • Chlorophyll • Oil Pollution	One prototype instrument exists and operates at one Fraunhofer line at a time. Up to three different lines are available. Instrument has been flown in a helicopter for monitoring rhodamine dye in concentrations of less than 5 ppb over various marine areas.	An improved model may possibly be applicable for monitoring spatial distribution of phytoplankton by means of chlorophyll fluorescence, as well as for monitoring oil spills by crude oil fluorescence. Extensive development required for space deployment.	The fluorescence coefficient (at 5890 to 5892 Å) of the water target is measured; this is the percent of incident sunlight returned from the target as fluorescence. It is automatically computed as equal to the total percent of incident light returned from the target minus the percent returned as reflectance and backscatter.

SECTION 6

DATA STORAGE, TRANSMISSION AND PROCESSING

6.1 INTRODUCTION AND BACKGROUND

The reviewed literature, the inputs from the questionnaires, and the interviews produced little detailed information regarding the amount of remotely sensed data needed to satisfy oceanographic applications. By detailed information is meant the sampling rate and number of data bits needed to provide the measurement density and required accuracies as indicated in Section 3. The literature also revealed that little work has been done by the individual experimenters in the areas of data storage and transmission of data gathered by spaceborne sensors. Indications were that the experimenters felt it is premature for such studies in light of sensor and signature analyses development status.

Two separate panels of the National Academy of Science (NAS) Summer Study Group did, however, study the problems involved. Panel 6 (78) was convened in 1967 and devoted considerable effort in the area of data handling. As a result of the findings of Panel 6 and others in the 1967 meeting, Panel 8 (79) was constituted in 1968 to consider the problems and issues raised by the previous sessions in the field of the distribution of remotely sensed information. The result of these studies is discussed in the succeeding paragraphs.

6.2 DATA SYSTEMS AND DATA PROCESSING

Panel 6 (78) obtained user data requirements from the panels that had studied the priorities of collecting Earth resources data by remote sensors, in order to develop a conceptual design for a data transmission, storage and processing system. Unfortunately, the oceanographic and meteorology panels did not provide data requirements; therefore, the study lacks their unique requirements, particularly in the area of real time data. However, it is considered that in general the data systems requirements are comparable and thus would be applicable to oceanography with suitable

modifications. Using the data requirements of the users, the NAS Panel 6 developed first and second generation systems for data handling. These systems are briefly described below.

6.2.1 First Generation System

The first generation system is designed for data dissemination on a quarterly, or at most, monthly basis, therefore it would require modifications to provide the oceanographic community with data they required in real or near real time. For example, because of the rapidly changing nature of the oceans surface, those users requiring information on its state of roughness must receive it on a near real time basis if it is to be of use to them in their operations.

In the first generation system the sensors considered are: photographic cameras, TV cameras (vidicon), and side-looking radars (SLR). Figure 6-1 depicts the data link and data processing system. Data link and data processing requirements for this system will most likely be limited to an FM telemetry system of ~4.5-MHz bandwidth. Coverage can be handled by two or three ground stations. The first generation stations would be equipped with FM receivers and analog recorders. In addition, they would have a limited optical processor lab to accommodate map generation of the side-looking radar and the images generated by the vidicon camera.

The first generation data systems requirement appears to pose little or no problem to the state of the art in any facet of the related areas. The required telemetry systems have been flown, the ground-station requirements exist or can be obtained, and the computer and peripheral equipments are available. The principal emphasis must be placed on data management and the generation of software for indexing frames as received, and establishing a storage and retrieval system for immediate access of individual frames. A procedure, either software or through the use of peripheral imaging systems, for generating uncontrolled mosaics on a selected basis and for generating multicolor prints from single-color frames must also be developed. The former can be improvements in the Weather Bureau CDC 6600 rectification and mosaicing programs. The latter will require development of special hardware

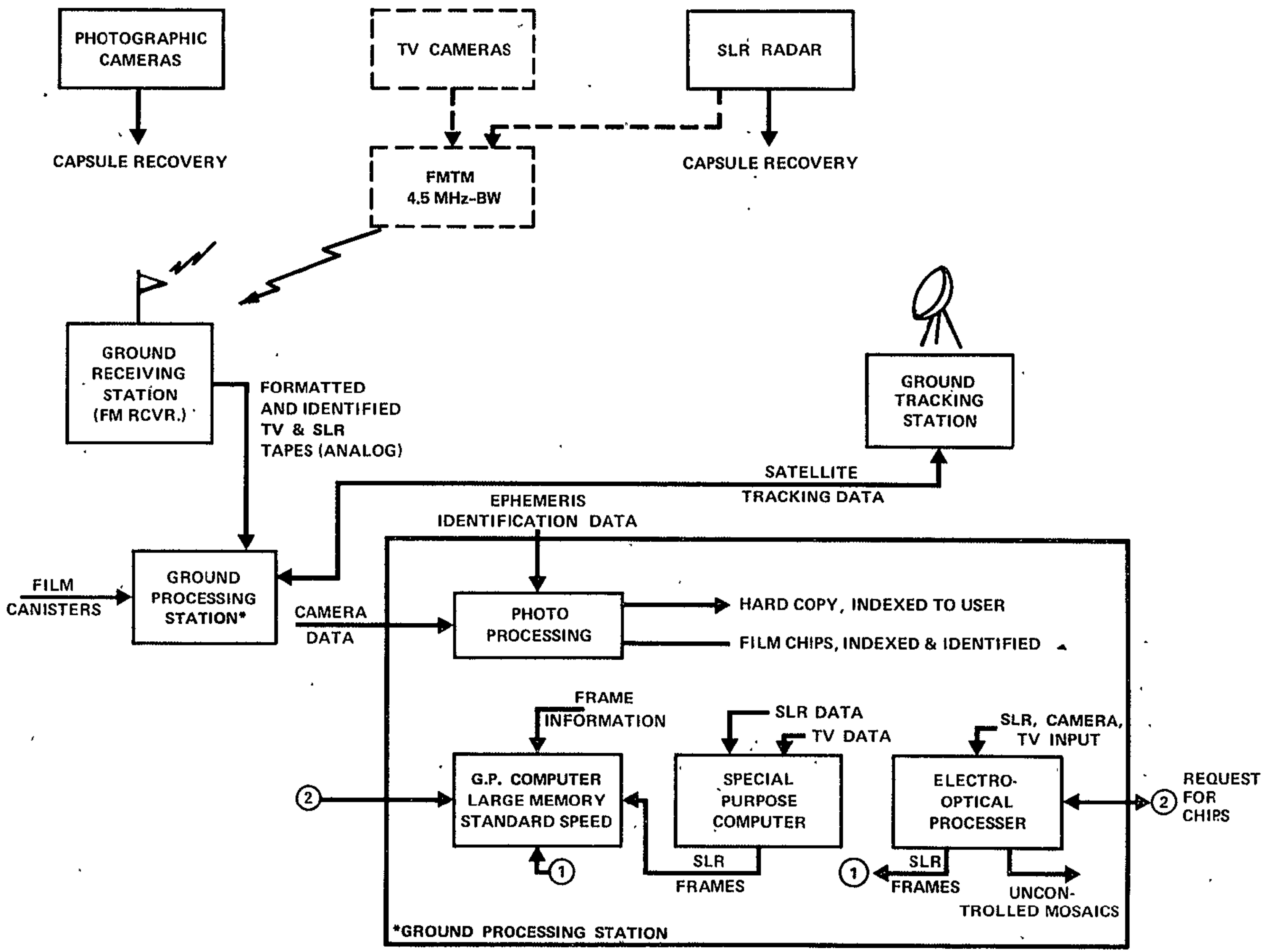

FIGURE 6-1 First-generation data link and data processing. (78)

for correcting the camera biases and nonlinearities and for the rapid registration of images. It will require the development of a wide-band recording medium (storage tube).

A program for the planned growth of the ground data-processing station must proceed in parallel with that of the satellite system. As the latter evolves through successive generations, each more sophisticated than its predecessor, so must the data-processing system evolve in order to realize the maximum in information yield promised by the more elaborate and presumably more capable sensing systems.

6.2.2 Second Generation System

A second generation system as envisioned by the various disciplines allows a better utilization of the data-systems technology. It takes advantage of the significant advances made in recent years in the development of computers and methods for data analysis.

Numerous sensors have been suggested to obtain both radiance and spectral reflectance measurements from which characteristics of the imaged area can be determined for subsequent classification. The introduction of multiple sensors is expected to increase the data-link requirements.

The hypothetical system (see Figure 6-2) includes high resolution (30 m cells) and swath widths of 160 km with 6 bits per sample for each of the following:

Line (slit) Scanner
Multispectral Radar
High-Resolution Infrared Radiometer (HRIR) and Medium-Resolution Infrared Radiometer (MRIR)

As discussed in Section 5, these sensors have application to ocean studies. Due to the high resolution and possibility of an automatic digital-computer processing system, these instruments are candidates for pulse-code modulation (PCM) transmission. For a 90-min orbit, each will require a link with 1.12×10^6 bits per second (bps) capacity. These link capacities are reasonable near-term expectations.

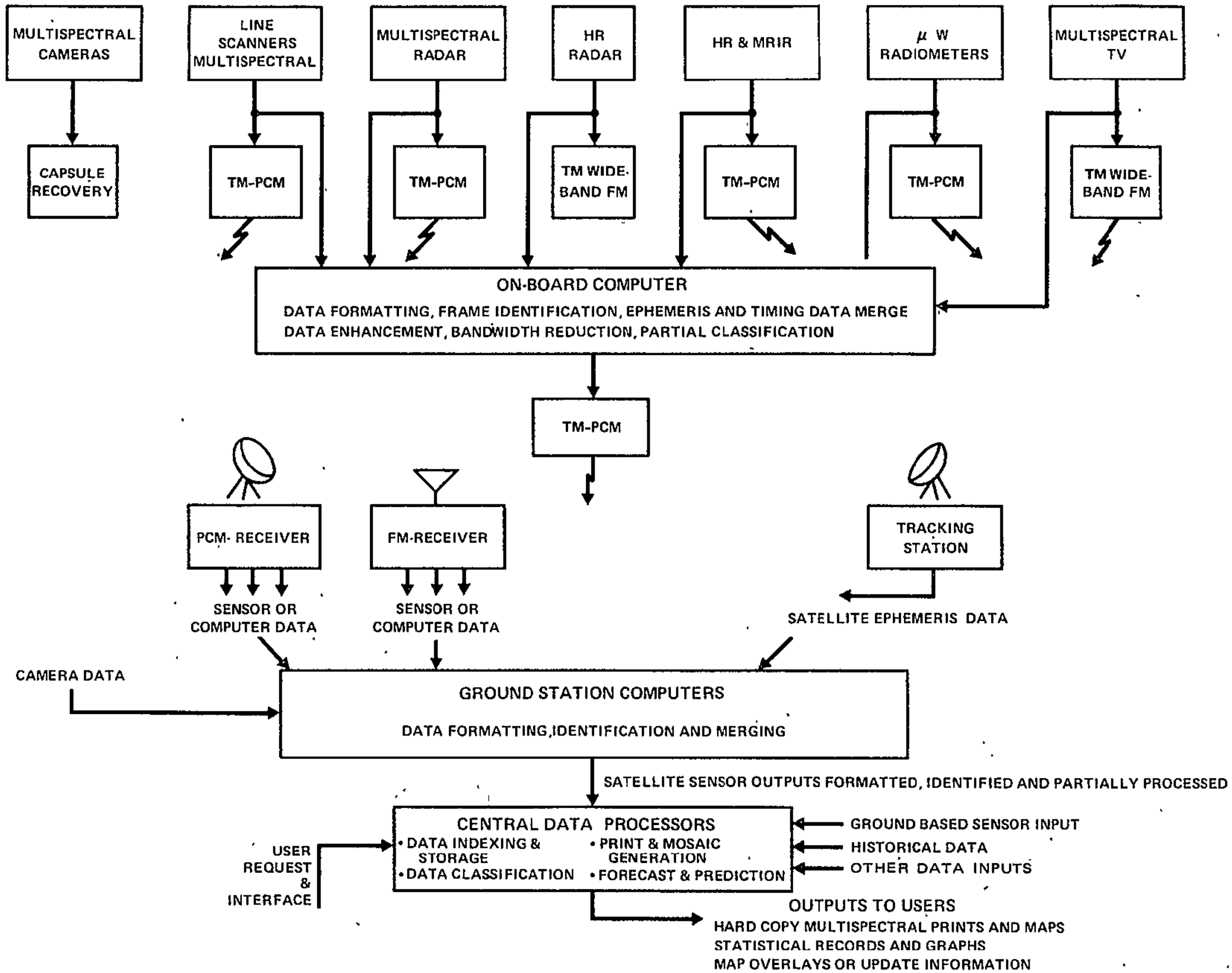

FIGURE 6-2 Overall view of second-generation system. (78)

Multispectral TV and high-resolution radar are candidates for FM transmission with an expected bandwidth of 200 KHz or more. Passive microwave requirements are comparable with "housekeeping" bit rates and can very likely be subcommutated on the PCM links. Duty cycles for the several candidates of a PCM transmission are not determined at this time; however, time multiplexing via stored-program variable-format PCM systems is a possibility worth exploring once these duty cycles have been established.

In those cases where excessive bandwidth may be required, such as for the photographic camera systems, the use of multiple reentry systems can accommodate the needed data acquisition if the frequency of data acquisition is not too high (i. e., monthly or quarterly). The possibility of on-board processing for portions of the data acquired may be of further use for both bandwidth reduction and reduction of ground data-processing requirements.

With the availability of large memory capacity computers with rapid processing (see Table 6-1), a significant amount of data processing can be accomplished on board the vehicle. The relatively high bandwidth requirements make real-time data compression attractive. The basic reason for real-time processing is to avoid saturating the parallel input-output capacity of the computer which is occasioned by slow digital tape deck transfer rates and the resulting excessive tape handling problems. The only decision is whether to do this in orbit or on the ground. Obvious weight and power considerations favor the ground installation, However, since three ground stations may be required, the equipment necessary to relieve the awkward tape logistic and handling problem (20 megabits per second is approximately one 800-bits-per-inch (bpi) digital tape every 5 sec) must be provided in triplicate or the equivalent in analog tape must be shipped physically to the processing center. Further, the real-time processing effects no bandwidth savings in the orbit to ground-level bank.

Real-time processing in orbit, despite the disadvantages of adding to the vehicle weight and power consumption, is attractive from the standpoint of bandwidth savings. No attempt will be made here to separate those tasks that can be done on board the vehicle from those relegated to ground-based

TABLE 6-1

SPACEBORNE COMPUTERS (79)

Characteristic	Current[a]	Projected 1970-1975
Core size	131 K @ 32 bits	250 K
Word lengths	16, 32, 64, 48, 30	Same
Memory cycle	1.0-2.0 μsec	10^{-3} μsec
Index registers	8-16	Same
Add times	1.0-5. μsec	10^{-3} μsec
Multiplication times	6.5-18 μ sec	6 x 10^{-3} μsec
Division times	8.0-32. μsec	8 x 10^{-3} μsec
Floating points	Hardware	Same
Elementary functions	Hardware	Same
Weight	75-520 lb	
Volume	1.8-7.0 ft^3	
Power	365-809 W	

[a]The specifications given here are composites and represent reliable "on the shelf" computers used in aircraft and proposed for existing orbital vehicles; they do not represent "state of the art computer technology.

processors. Rather the discussion will consider the multispectral and multisensor processing that can be accomplished.

The system envisioned for the second generation system will take the form shown in Figure 6-2. The detailed discussion of the data processing implied is beyond the scope of this discussion. The intent here is to give some insight into the kinds of data processing and data reduction that are required for this system. At first glance it would appear that the volume of data that can be acquired would soon cause a bottleneck that would nullify the wide and repeated coverage achievable from the satellite. On the other hand, the first generation system will have, by this time, established a procedure for handling the incoming data and assuring that users are provided hard

copy on an immediate routine basis. The expected increase in volume and type of imagery to be made available will involve some drastic changes. One line of flow should be open, that of generation of copies of the original imagery properly annotated and indexed and stored in a readily retrievable format. This portion of the data-processing system can be expanded at a more leisurely pace, commensurate with the increase in data-input rate. The peripheral equipment that has been used to generate hard copy, film clips, and uncontrolled mosaics from the TV camera, SLR, and photographic imagery has immediate use in the second generation system. It will form the focal point for the expansion of the equipments and activities to handle the multispectral, multisensor data anticipated.

Fortunately, it is not likely that each user will want all the data immediately after it has been acquired. Rather it appears that specific users will have identified sensors that benefit them most and require a quick turn around on that data only. They may request additional data, but they will be willing to accept this on a less timely basis, since it will be needed principally for support or verification, or may be required only for their academic, or long-range scientific interest. Other users have requirements that are met by an intensive effort for a short period of time at infrequent intervals (seasonal variations, for example). Their need is immediate, and acts more as an impulse than as a step function input on the work load. Provisions must be made to introduce the additional processing equipments needed for the short-period, high-quantity data handling. Those users who have specified the needs for multispectral or multisensor imagery on a routine basis, at shortly spaced intervals, will pose the greatest demand on the processing centers, since this type of data (imagery) is the most difficult to accurately and rapidly process. It is here that the automated data handling and data processing should offer the most benefit. After this processing phase, the output is no longer the sensed signal converted to a form that is manageable by a user, but which leaves all manipulation, conversion, and computation to him. The possibility will now exist for preparation of annotated maps, the prediction of sea states on shipping lanes, or storm warnings in the tropics. The users, both scientisits and laymen, can then be provided with meaningful information on a timely basis. The

response of an automated data-handling system is not to be limited to processing requests for data desired from a fixed-cycle data-gathering system. Indeed variable formats, raised on command to accommodate special critical needs are within current capabilities, and there is every indication to support the belief that the development of this feature will expand between now and the near future.

6.3 POTENTIAL SYSTEMS FOR REMOTE SENSING INFORMATION AND DISTRIBUTION

As previously mentioned, Panel 6 (78) and the other panels of the Space Applications Summer Study (1967) indicated a need for further consideration of the transmission, handling and distribution functions for data derived from remote-sensing platforms. Panel 8 (79) convened in 1968 to consider these problems. As did its predecessor, it considered the requirements of the total community of users of Earth-Resources Data and did not direct its attention solely to the oceanographic community. However, useful information on transmission, handling and distribution of oceanographic data can be derived from this study.

The report states that early estimates of data volume and of the potential data-processing requirements led to the conclusion that a very substantial roadblock to the use of the data could lie in the present capability for data processing. For example, imaging sensors operating at 5-MHz bandwidth can readily produce quantities of digital data of 10^{12} bits per day. If detailed digital processing of all these pieces of information is required, one can quickly run out of computer capacity, even with very large machines. In view of this, the Panel's earliest considerations probed the extent of need for detailed processing of the data. The consequence of these assumptions is that data will enter the first-generation data-handling function from aircraft and satellite data-gathering sources. The largest single source of data will be the satellite imagery data. The processing of this latter data in analog form only produces an output product that lacks much of the value that one can anticipate for future systems which incorporate image enhancement and automatic analysis and measurement techniques. The Panels judgment is that this early product would however have significant utility, and not require large

amounts of training for its limited use. Beyond that, an aggressive R&D program should be mounted to upgrade the earliest standard-output products, and to develop advanced uses. The conviction, in part, forms the basis for assumptions with respect to the experimental access to the first system. Based on these assumptions the Panel developed five possible systems configurations for acquiring, transmitting, processing, and disseminating remotely sensed Earth resources data. These were total systems for all of the user communities, including the oceanographic community, and include the following components:

1. Aircraft and spacecraft systems containing remote sensors and supporting equipments;
2. Data-receiving centers;
3. Data-processing and analysis centers;
4. Distribution networks; and
5. Archives.

6.3.1 System I

System I consists of a high-altitude aircraft in which all data obtained are stored on board (film or magnetic type) and are physically delivered to the regional center for developing, copying, and final delivery to the user.

6.3.2 System II

This system is similar to System I except the vehicle is a recoverable satellite equipped with film metric camera(s). Upon recovery of the satellite, or payload, the exposed film is physically delivered to the center for processing, copying and distribution.

6.3.3 System III

System III is designed around a long-life, unmanned, non-recoverable, direct readout satellite. This basic system is further subdivided into three variations dependent in the manner in which the data are transmitted.

6.3.3.1 System IIIA

This system provides for direct regional readout and would communicate its data in real time directly to the ground. Ground stations with tracking antennas receive data from the satellite when its orbit ground-track is within 800 km of the station. Thus, the area coverage per ground station is about 2.6 million square km, requiring four to six ground receiving stations for the United States and Alaska; 20 stations for North and South America; and 100-120 stations for the world's land masses and oceans. This system fits in well with regional (rather than central) processing and analysis centers, with the regional processing center placed at the same location as the receiving ground station. The satellite design is simple. The transmitter is sized for a 1600 km distance between a 2- to 3-dB fixed spacecraft transmitting antenna and a 25- to 30-dB automatic-tracking receiving antenna. The satellite design is, to a large degree, independent of other systems (e.g., communication relay, satellite networks, and number of ground receiving stations).

Should it be desired to have all or some of the processing functions performed at one central station, the four to six U.S. regional ground receiving stations could relay their information to the one central U.S. processing station via ground links or a geostationary communications relay satellite.

Participation of foreign countries could be accommodated by the emplacement of combination ground receiving and processing stations within the participating countries. (The concept of a ship-borne or mobile station for temporary use in different parts of the world suggests itself.)

6.3.3.2 System IIIB

In this system, real time readout of data is obtained via a network of geostationary communication relay satellites. The relay satellite, in turn, relays the information to one (or more if desired) central receiving ground stations. Thus, with the use of a geostationary relay satellite network consisting of 3 satellites, a single remote-sensing satellite could deliver global data in real time to a central ground station. The remote-sensing spacecraft must have sufficient transmitter power for a 40,000 km range between the tracking transmitting antenna and the large fixed-area antenna on the communication relay satellite.

Processing of all the global data could be accomplished at a single receiving and processing center. Dissemination of copies of the data to the user groups can be accomplished by either mail or radio frequency links if a real-time requirement exists.

Assuming the prior establishment of a Geostationary Communication Relay Satellite Network, System IIIB is the most economical and straightforward way of initiating a global monitoring capability.

6.3.3.3 System IIIC

In this option, the ground receivers of IIIA and the direct readout from the satellite would be supplemented by satellite on-board magnetic-tape recorders for the acquiring of data at locations distant from established ground receivers. One assumes the existence of an additional recorder on board to provide a back-up capability. The reliability of the recorders and their operational life becomes a major consideration. Assuming that this can be handled adequately, the system would use two to three domestic receiving stations for repetitive U.S. coverage, and selected use of the recorders for coverage outside the United States. This option appears to provide the cheapest entry to a quickly growing program and was assumed throughout our further discussions as the likely imagery option. It has the advantage of real time readout in areas where the satellite can communicate directly, such as with shipboard centers, and of near real time readout of the remaining areas of the Earth's surface.

6.3.4 Summary

In summary, this report establishes the requirements for a Data-Processing Center for a global network of sensors that would fulfill the requirements for Earth resources data for the total user community. This network would consist of land-based stations, ocean-and lake-based (buoys), and atmospheric (balloons) platforms. The positions of most of the platforms will be fixed and known. Some platforms (balloons and drifting buoys) will have time-varying positions. There will be a large variation in the number, type, and frequency of measurements taken on each platform. For example, ocean buoys will act as platforms for a whole complex of oceanographic and meteorologic instruments that will require

a rather long communication message 4 times per day. Estimates of the size of the first generation system are:

a. Number of platforms ~20,000;

b. Number of messages/day ~40,000; and

c. Number of bits/day ~10 million.

The main elements of the Distribution Sensor System (see Figure 6-3) are presented below:

1. The network of distributed sensors or automated instrument platforms; and

2. Communication relay satellite(s).

3. A group of governmental agencies with the responsibility, facilities, and organization for (a) monitoring and analyzing various data such as remote sensing, manned observation stations, automated instrument stations; and (b) distributing basic data and analyses to various established users -- other government groups, industrial, educational, and private groups and foreign groups.

4. A data-processing center or centers for (a) receiving observational data from remote-sensing spacecraft and distributed surface sensors; (b) organizing the data for dissemination to the various government agencies, e.g., ESSA, Dept. of Interior, NAVOCEANO, and for archiving; and (c) monitoring performance of and providing programming and scheduling control of the spacecraft data-collecting functions.

With respect to the data from the distributed sensors, the processing center must provide the services listed below.

1. Receive and decode the radio frequency signals relayed by the communication satellite.

2. Change the format of messages, if necessary, For example, the single message from the ocean buoy may have to be reformatted into two separate messages -- one containing the meteorological information, the second containing the oceanographic information.

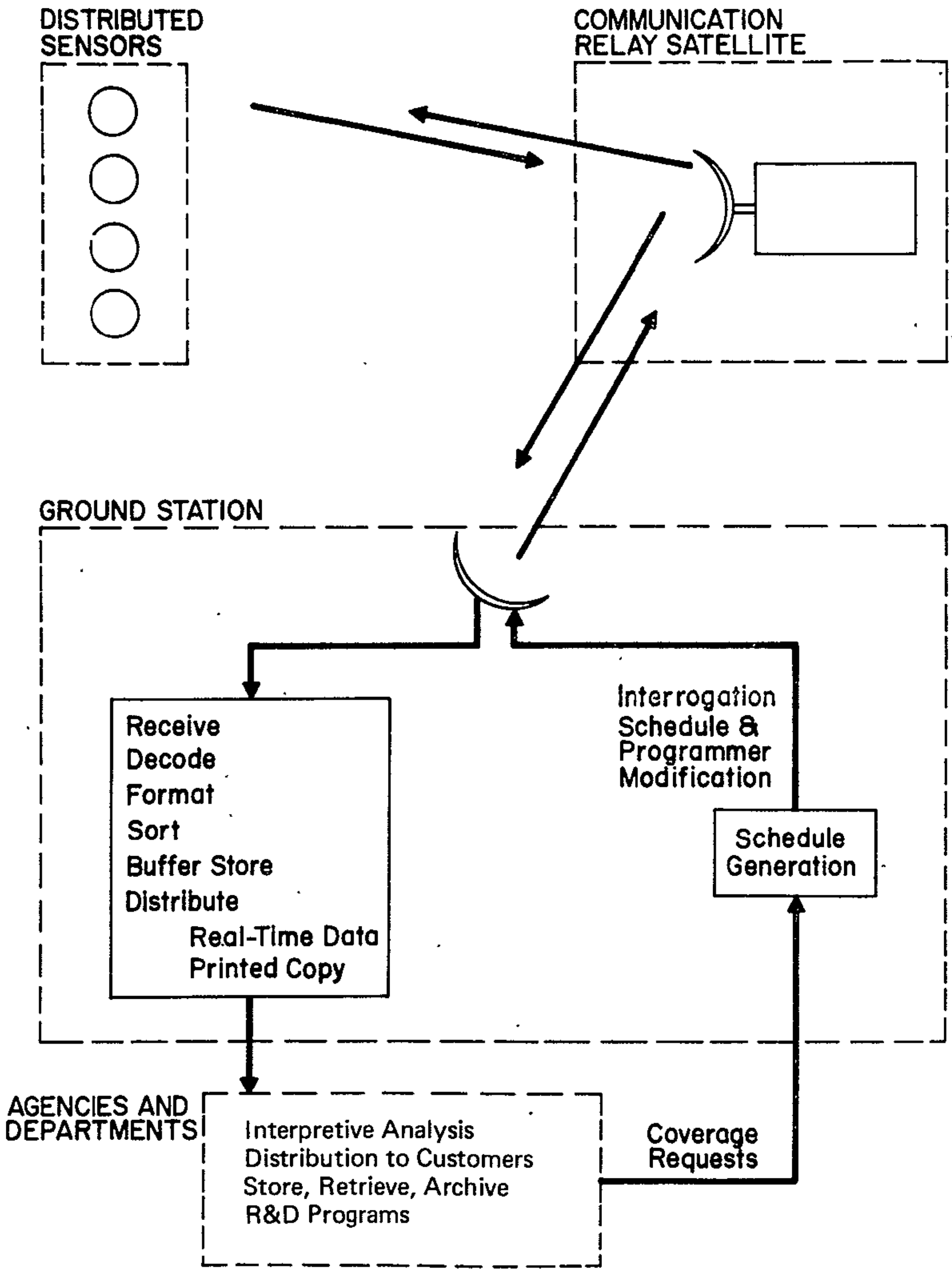

FIGURE 6-3 Functional system description - distributed sensors. (79)

3. Sort and store the messages into groups for dissemination to the various user communities.

4. Distribute some of the information, e.g., weather data, in near real time (perhaps computer to computer) over hard wire links.

From a data-processing standpoint, a single center processing global information requires the receipt, formatting, sorting, forwarding, and printing of about 40,000 messages per day (10 million bits), and the generation of a comparable number of interrogation-command schedules. The volume and the type of data manipulation required, are small and simple compared to the capacit and capability of modern high-speed computer and central-processing units. The spacecraft data-processing center will have at least one central processing unit; the load imposed by the distributed sensors would require only a small fraction of the time of such a unit.

The conclusions of Panel 8 (79) are:

1. A relatively simple straightforward data-handling system can be put together in a time schedule that matches the first Earth-resources satellite needs.

2. That, for full realization of the benefits of data-handling techniques, both in the rapid evolution beyond the first systems, and in the development of new applications, a significant, well-managed program of R&D organized to recognize priorities is required.

3. That significant improvements will be possible in the data-handling capabilities and products. These will include extended capabilities for machine-assisted interpretation, some automatic interpretation, extended archival capabilities, and dramatically increased computational and display applications. It is envisioned that these improvements in a second data handling system would be in operation in 5 to 7 years after the start of the first system.

In addition to the above, both panels stressed the fact that much research is required in the area of signal analysis and interpretation. Thus with the vast amount of data that will become available from satellite observation an extensive training program will be required to provide competent personnel to effectively analyze the data.

6.4 CONCLUDING REMARKS

Other than the National Academy of Sciences Study, the remainder of the reports, the questionnaires and the interviews provided little information or requirements for and status of development of data storage, transmission and processing techniques or equipment. Several reports recognized that operational Earth Resources satellites will generate great quantities of data which will create an analysis problem. None of them developed the subject sufficiently to add to the results of the two studies discussed above. Few of the individuals interviewed could provide quantitative requirements. Our investigations indicate that these individuals have not determined sufficiently their experimental data requirements, hence they cannot, at this time, estimate their operational requirements. When specific experiments are designed, the number of data points and amount of coverage required will be determined, and the number of data bits to be acquired can then be calculated. With this information, trade-off studies will be required to determine the most effective mix of on board storage and processing versus direct transmission of raw data for ground processing. Simulation studies can and should be instituted now to provide bounds to the problems.

In the past, data storage and transmission systems for many scientific satellites, have been developed independently of the experiments, thus the experiment then had to be designed around the given capabilities of the system. This is obviously not the optimum procedure to follow since it limits the amount of data that can be acquired. It is dictated, however, by state of the art components, dump stations, bandwidth allocations, tape recorders, and other factors. CSC believes that most of these type problems are not included in the scope of SPOC's activities.

Specific conclusions by CSC are:

1. Little progress has been made in the area of determining the data storage, transmission, and processing requirements for oceanographic data. This area of activity should be pursued by SPOC, in the near future, so that the requirements of the oceanographic user community can be utilized in the design and development by NASA of data handling equipment.

2. The concepts for data storage, transmission, and processing as developed by the NAS study may satisfy the requirements of the oceanographic community.

3. R&D efforts should be initiated, by the cognizant agency, i. e., NASA, toward developing more reliable and efficient data storage devices, transmission systems, processing systems, etc.

SECTION 7

BENEFITS

7.1 INTRODUCTION

Since early in the 1960's, as the possibilities of using satellites for surveying and observing the Earth and its oceans became evident, there have been attempts made to express the possible benefits to be gained in terms of the commonly accepted standard, the dollar.

In the many studies made to assess the opportunities for satellite remote sensing, invariably a section has been included on "Economic Benefits." As these studies progressed it became clear that any attempt to quantify benefits in terms of dollar value was subject to many assumptions and preconditions. In some cases the benefits could never be expressed in monetary terms. For example, how much value could you place on a life saved by an early storm surge or tsunami warning? In general, however, one can put a value on a country's total fish catch, or the number of ship hours saved in an oceanic transit free from storms or high seas. And, quantitative values have indeed been projected for satellite contributions to such endeavors. But in almost all cases, the unknown preconditions cause the investigators to place important caveats on the values. In fact, to be blunt, one can assign almost any dollar value he desires to the economic benefits to be gained from an oceanographic satellite system. In some cases the benefits for a satellite system appear scant when one type of user is considered; therefore, many types of users are evaluated for benefits and the sum is considered. However, data requirements of different user types are so diverse, as is shown earlier in this report, that it becomes obvious that no one system, in the near future, will satisfy them. Therefore, the concept of total economic value of a particular satellite system is meaningless.

While the above statements appear negative in outlook, the opposite is true. No development program, or exploration is undertaken, in reality, when the benefits are assured to be greater than the costs. But in the case of remote sensing, one thing is certain; there will be an economic payoff. What is largely unknown is "how much?" This study attempted to identify those benefits which

were suggested in the published literature and those which interviewees could provide.

7.2 BENEFITS IDENTIFIED IN LITERATURE REVIEW

The literature search for potential benefits derivable from satellite gathered oceanographic data left much to be desired. Only 14 of the documents reviewed discussed benefits and most of these were discussed only in a philosophical manner.

In 1964 the National Academy of Sciences conducted a study, Economic Benefits from Oceanographic Research (75). This study did not consider the benefits derivable from satellite sensing per se, but devoted its attention to estimating the overall benefits that could be derived from oceanographic research and thus presents a good base to establish the total benefits obtainable through oceanographic research.

This study delineates six possible areas in which oceanographic research would provide benefits. These areas and the estimated value of possible benefits are tabulated below:

TABLE 7.1
ECONOMIC BENEFITS FROM OCEANOGRAPHIC RESEARCH (75)

Application Area		Economic Benefits	
		Annual Savings (Millions of Dollars)	Annual New Proceeds (Millions of Dollars)
Fisheries	Domestic		$ 380
	Worldwide		175
Marine Mining			190
Shipborne Foreign Trade		$ 890	
Long-Range Weather Forecasting		2,000	
Near-Shore Sewage Disposal		80	
Near-Shore Recreation			2,000
Totals		$2,970	$2,745

The portion of these oceanic benefits that might be provided by space system technology is only conjectural at this time, but some attempts have been made to determine them and are discussed below.

A 1966 study by the University of Michigan, Peaceful Uses of Earth Observation Spacecraft, (155), states that benefits would accrue from spacecraft oceanographic data by improving long-range weather forecasting. The detection of pollution would provide benefits to the recreational users of the ocean shorelines and the fishing industry would benefit through the location of potential fishing areas. No monetary benefits for oceanography were presented.

A General Electric report, Space/Oceanography Study, (36), prepared for the National Council of Marine Resources and Engineering Development in 1967, estimates that information gained from space oceanographic observations may be applicable for fishing, namely:

(1) Establishing a census of schooling fish by fishing area, and

(2) Monitoring violation of national quotas and enforcement of international agreements.

This report estimates benefits in 1975 of $215 million to the U.S. and $2.0 billion worldwide. This study also states that benefits will accrue to the marine transportation, offshore mining and petroleum industries but does not provide monetary values.

A Stanford Research Institute Study (128) estimates that a Manned Orbital Research Laboratory (MORL) could effect tangible benefits in oceanographic data gathering surveys of $2 million per year in ship operating costs and an additional $2 million by eliminating the need of data buoy network on the high seas. In the field of transportation, the report estimates savings of $8 million per year. The data obtained by the MORL would contribute estimated annual benefits of $50 million to the fishing industry and savings of $1 million to those engaged in coastal studies according to the Stanford study.

A Study of the Economic Benefits and Implications of Space Station Operations, prepared for NASA by the Planning Research Corporation (PRC) in 1968 indicates that benefits for Earth resources studies would accrue in numerous areas. In the oceanographic field, iceberg detection is discussed.

The feasibility of detecting icebergs using spaceborne sensors is rated high, but the benefits are estimated as insignificant. In the discussion of improving nautical charting it is pointed out that in the highly traveled areas the charts are good, most casualties occur because of personnel error or lack of knowledge of the ship's position, the poorly charted areas have a low volume of traffic, therefore few casualties. The feasibility of improving charting, utilizing spacecraft is rated high but the benefits accruing from reduced casualties is given as only $9 million per year. A third benefit area indicated in the PRC study is in improved weather routing of ships. The feasibility of improving weather routing is stated to be high and the estimated savings total $7 million per year. In the area of water pollution the feasibility of using satellites in pollution studies is rated medium and the savings, which are based on a reduction of the number of ground sampling points by 25% would amount to an estimated $6.4 million per year. However, as many of these would be on inland streams and lakes, the total savings would not be in the field of oceanography. In the area of national disasters such as tidal waves, hurricanes, volcanoes, earthquakes, the study states no monetary benefits would result, but estimates that about 300 lives would be saved each year. Search and Resue at sea utilizing satellite sensors and locators is estimated by PRC to be capable of producing estimated benefits of about $38 million per year and an annual saving of approximately 2,500 lives.

In the course of the PRC study several Earth resources case studies were conducted to determine potential benefits. In oceanography, the case study was conducted for Albacore tuna fishing in the Pacific Ocean. The system envisioned involved the attaching of a sonic transducer to the tuna which would be detected by ocean buoys which in turn would be monitored by a satellite thus establishing the migration movements of the fish schools. Additionally, the available food, both for the larva and fish would be measured, and when required, necessary steps would be taken to increase the food supply. The study indicates that benefits to the Pacific tuna industry would amount to some $156 million per year. The study then projected this for all commercial fishing and arrived at an estimate of $1.56 billion per year.

The National Academy of Sciences' Panel 5 Report on Oceanography (77), one of the more authoritative sources reviewed in this study, notes that economic benefits will accrue in many areas but the only monetary figure stated is that probably \$300 million to \$600 million would be saved by improved ship routing. This can be compared with the 7 million dollar estimate indicated in the PRC report.

The Summary of the NAS Panel 5 Report (81) accepted the estimated benefits developed by other panels such as forestry, agriculture, geography, and geology, but ignored oceanographic benefits. Instead, their conclusion was:

> "In the long run, benefits from satellite oceanographic techniques can be expected in many large sectors of the economy, such as fisheries, coastal engineering, recreation, and ocean transportation. Since these benefits are so far in the future and depend on concepts still speculative (both in feasibility and application), there has been a valid reluctance to estimate tangible values. However, one example may be noted:
>
> In 1965, the world fishing catch was about \$4.2 billion. In 1964 the U.S. in-shore ocean market was \$4.0 billion. Hence, it seems safe to assume that any small percentage savings accruing to industries would quickly give benefits many times greater than the cost of a satellite program."

As a further indication of the National Academy of Science's reluctance to establish benefits of space gathered information an excerpt from the Report of the Central Review Committee (80) is quoted below:

> "The Study invited a number of economists and economist-engineers to analyze the systems postulated by the Panels, to estimate the costs of development and operations, and to appraise the foreseeable benefits. Their tentative findings were, in turn, reviewed in the 1968 summer session by an Economic Analysis Panel and by several consultants to the Central Review Committee.
>
> The consensus was that these new and challenging fields of satellite and sensor technology are advancing so rapidly that caution must accompany any attempts at economic appraisal: the conventional cost-benefit analysis approach is not suitable for judging technologies in the fluid, formative state. Instead, in evaluating the different space applications, we were advised to use guides that have been widely adopted by business for planning and developing new products, processes, and services. The method comprises a sequence of four steps, interspersed with evaluation before each successive commitment, and usually spread over five to ten years.

1) Basic and exploratory research

2) Development: early design, limited testing

3) Pilot plant: market-testing programs

4) Operation: design, construction, and operation of commercial plant.

The basic-research commitment involves substantial risk; cost and benefits are highly conjectural; judgment is necessarily the determinant. On the other hand, basic research is the least expensive stage. Subsequent to it, facts begin to accumulate, providing increasingly accurate material on which to base appraisals. By the time the greatest commitment is needed, the relevant costs and benefits can be defined, and sufficient data are available to aid the decision-maker.

Many of the space applications studies by the Panels fit into this sequential rationale. Some are challenging but of uncertain benefit; some warrant consideration of funding; others merit support now in competition with other pressing demands."

Of the remainder of the documents reviewed, very few considered benefits accruing from spacecraft oceanographic data. Those that did (8, 24, 19, 26, 36, 37, 44, 77, and 117) stated that benefits would accrue to the marine transportation and fishing industries, weather forecasters and to scientific knowledge, but did not quantify any of them.

7.3 BENEFITS IDENTIFIED DURING STUDY

A part of the questionnaires and interviews described in Section 2 concerned benefits. The results were in keeping with what had been anticipated. Many of the individuals contacted indicated that benefits would result from spacecraft sensing of oceanographic data but none were willing to quantify benefits. During the interviews special efforts were made to obtain quantified benefits information but all of those interviewed were reluctant to even hazard a guess. Thus little new in terms of benefits information arose as a result of the present study.

7.4 CONCLUSIONS

Remote sensing by satellite offers the only potentially reasonable means of obtaining many types of information concerning the sea on a worldwide and/or repetitive basis. This fact is well recognized. It is also well recognized that satellite data is potentially of great use to fisheries, marine transportation, and other industrial users. Moreover, these industries are recognized to be of large economic importance. In addition, oceanographic satellite data is expected to contribute substantially to our understanding of the dynamics of the ocean and of weather. On these bases most knowledgeable individuals are willing to conclude that satellite remote sensing of oceanographic parameters will have an economic value considerably beyond the cost of the program.

On the other hand, we are at the "Basic and exploratory research" step of the four-step sequence described in the National Academy of Sciences report.

As a result it must be concluded that at this time, though economic benefits appear to exist, there is insufficient information to quantify them. For example, experts working in the field realize that sea surface temperature, salinity and chlorophyll do have a direct relationship with fish population. However, the state of the art of predicting what combination of these will insure the location of fish and the capabilities of remote sensors to collect data which will define these conditions is still too uncertain to determine benefits with any assurance. Likewise, the marine transportation industry recognizes that weather routing produces savings both in transit time and ship and cargo damage reductions. However, they do not know how much improvement space collected data will make to current weather predictions and therefore, cannot, with any assurance, quantify the benefits that would accrue. Until such time as a system is operational the only way to estimate quantitative benefits requires so many assumptions that the results are nearly meaningless.

SECTION 8

EVALUATION OF SPOC SPONSORED EFFORTS AND CONCLUSIONS

The objectives of this section of the report are twofold. In Subsection 8.1 SPOC efforts for the period January 1965 through July 1969 are summarized and evaluated in the context of the overall development of the field of spacecraft oceanography as presented in the previous sections of the report. In the remainder of this section conclusions are presented relative to each of the topics discussed in Sections 2 through 7 of this report.

8.1 EXPERIMENTS/INVESTIGATIONS SPONSORED BY SPOC

During the course of this study 75 documents which had been sponsored or monitored by SPOC were reviewed. These are indicated in the Bibliography. In order to analyze the SPOC efforts in terms of the results presented in the previous sections these efforts were summarized in matrix form in a series of three tables, Tables 8-1, 8-2, and 8-3. These tables characterize the efforts in terms of user community, oceanic phenomena sensed, and sensing instruments Forty three of the SPOC documents are included in the tables. The remaining thirty two documents did not lend themselves to tabulation in this format and consequently are not included in these tables. These latter documents are briefly discussed below.

References 2, 74, 117, 119, 120, and 162 consist of documents prepared by members of the SPOC staff and are reviews of progress and/or potential applications of remote sensing for measuring oceanographic parameters. They were either presented at professional meetings and/or published independently or in technical journals. These reports represent that aspect of SPOC activities related to informing the oceanographic community of the potential capabilities of remote sensing of oceanographic parameters and thereby stimulating activities in these areas. The work sponsored by SPOC, discussed in these papers, is represented in Tables 8-1 through 8-3 through inclusion of the original report presenting the work.

TABLE 8-1. INVESTIGATIONS SPONSORED BY SPOC-TABULATED BY PHENOMENA VS SENSOR

SENSOR	PHENOMENA												
	MARINE ORGANISMS	POLLUTION	TEMPERATURE	SEA STATE	CURRENTS	SEA ICE	ICEBERGS	HEAT EXCHANGE	COLOR	BATHYMETRY	SEA SURFACE TOPOGRAPHY	BOTTOM CHAR-ACTERISITICS	SALANITY
MULTI-SPECTRAL CAMERA	14, 21,22 23,51	51	3	112 144	144	144		3	14,21,22,23, 51,101,111, 112,113,115, 136,142	21 22 112 115		21 22 23 51	
RADAR-SCATTEROMETER, IMAGER, ALTIMETER				17,67 98,99 68							39* 67*		
MICROWAVE RADIOMETER			92	11, 45,92 153, 154		92							92
INFRARED RADIOMETER		142	18,38,63, 65,136,142		38	9		38 63 64 65					
MULTI-SPECTRAL SCANNER									101	101			
SPECTROMETER	8,10 14,18 104,138, 148	8 104							8,18,104 148				
TELEVISION	14		3,61		61			3					
LASER				110						101			

NOTE: Numbers relate to documents listed in Bibliography.
* Theoretical studies only.

TABLE 8-2. INVESTIGATIONS SPONSORED BY SPOC-TABULATED BY PHENOMENA VERSUS USER COMMUNITY

USER COMMUNITY	PHENOMENA												
	MARINE ORGANISMS	POLLUTION	TEMPERATURE	SEA STATE	CURRENTS	SEA ICE	ICEBERGS	HEAT EXCHANGE	COLOR	BATHYMETRY	SEA SURFACE TOPOGRAPHY	BOTTOM CHAR-ACTERISTICS	SALANITY
TRANSPORTATION				45, 67,68, 98,99		9			101	101 115			
FISHING	10,18, 24,26, 104,138	8	18,38,61	45, 67,68 98,99	38	9			8,14,18 21,22,104	101 115			
MAPPING HYDROGRAPHY					61	9			101 115	101 115			
OTHER INDUSTRY		8		45, 67,68, 98,99						101 115			
SCIENTIFIC/ CULTURAL	8,14,21 22,23, 51,104 138,148	8 51 104	3,18,38, 65,92,136 142,144	11,17,45, 67,92,98, 99,110,112, 112,123, 144,153,154	61 144	9 92 144		3 63 64 65	18,21, 22,23,51, 111,112,113, 136,142,148	101 112 115	39* 67*	21 22 23 51	92
WEATHER FORECASTING AGENCIES			3,38,63, 65,92,142, 144	92		9		63 65					

NOTE: Numbers refer to specific documents as listed in the Bibliography.
* Theoretical studies only.

TABLE 8-3

INVESTIGATIONS SPONSORED BY SPOC-TABULATED BY USER COMMUNITY VERSUS SENSOR

SENSOR	USER COMMUNITY					
	TRANS-PORTATION	FISHING	MAPPING HYDROGRAPHY	OTHER INDUSTRY	SCIENTIFIC/ CULTURAL	WEATHER FORECASTING AGENCIES
MULTISPECTRAL CAMERA	101 115	14,21 22,115	115	101 115	3,21,22,23, 51,111,112, 113,115,136, 142,144	144,142
RADAR-SCATTEROMETER, IMAGER, ALTIMETER	17,67, 68,98,99	67,68		67,68	17,39,* 67,*98,99	
MICROWAVE RADIOMETER	45	45			11,45,92, 123,153, 154	92
INFRARED RADIOMETER	9	38	9	9	9,18,38 63,64,65 136,142	9,38, 63,65
MULTISPECTRAL SCANNER	101		101	101	101	
SPECTROMETER	-	8,10,14, 18,104,138		8	8,14,104, 138,148	
TELEVISION		14,61	61		3,61	3
LASER			101	101	110	

NOTE: Numbers refer to specific documents as listed in the Bibliography.
* Theoretical studies only.

References 88, 100, 123, and 129 are professional papers prepared by various experimenters discussing work that was accomplished by them under contract to SPOC. These experimenters also submitted contractor reports to SPOC covering the same material. Since the contractor reports are more complete than the papers, they were chosen to be included in the tables. Thus, the omission of these papers prevented redundancy and permitted a clearer picture of the relative distribution of SPOC supported research.

References 93, 133, 134, 135, and 137 are preliminary status reports on work conducted under SPOC sponsorship. These reports document progress in ongoing contracts and the material included is subsequently documented in final reports which are represented in the tables. Again, the omission of these reports from the tables eliminates redundancy.

References 70, 71, 72, 86, 96, and 126 are compendiums that include progress of ongoing SPOC contracts. These reports include reviews conducted at NASA/MSC by the Earth Resources Program, and compilations produced by SPOC. Progress discussed in these reviews is normally documented in contractor final reports. All published final reports have been included in the tables. Again the aim was to prevent redundancy.

Several studies (47, 131, 143, 160) have been performed with the objective of determining surface truth data requirements and corresponding instruments for acquiring the data. The most comprehensive study was performed by IIT Research Institute (47) and addressed primarily the calibration of aircraft sensors, rather than the collection of oceanographic data. They discussed three sites, Argus Island, Bermuda, Point Barrow, Alaska, and Scripps Pier, California. Of these three sites only the first two have been utilized for airborne data acquisition. Scripps Pier, as far as can be determined by CSC, has yet to be overflown by NASA aircraft for data collection purposes. This report (47) documents requirements for instruments, personnel and operations schedules on the ground and airborne sensors and calibration equipment.

Of the remaining documents, 12 and 84 are bibliographies, 130 is an index of ocean features photographed from Gemini, and 73 and 85 are administrative documents. None of these are suitable for tabulation in Tables 8-1 through 8-3.

References 12, 84, and 130 again represent efforts by SPOC to inform the oceanographic community concerning remote sensing by collection and dissemination of information.

Table 8-1 characterizes, according to phenomena being sensed and sensor instrumentation, the 43 SPOC sponsored studies which lend themselves to inclusion in the table. It may be seen from this table that the majority of the SPOC sponsored work lay in four areas. The largest SPOC funded effort has been concerned with the use of photography for measuring oceanographic parameters. Following this in order of level of effort expended, are infrared radiometry and microwave radiometry. A reasonable effort has also gone into study of the application of spectrometry to oceanography.

Reasons for the large number of photographic studies can be suggested. The most obvious are the advanced state of development of cameras, the high resolution data that can be acquired combined with the variety of data interpretation techniques available, and the large number of individuals skilled in the analysis of photographs. This coupled with the problems of specifying optimum films, filters, and spectral bands, which are very important when photographing the water surface, may explain the extensive activity to determine the feasibility of oceanographic applications. The development of Gemini, Apollo, and military space photography may have also played a part as did the fact that in the past the oceanographic community has little used photographic techniques necessitating considerable effort to identify valid applications.

As a result of SPOC efforts as well as the efforts of others, numerous oceanographic applications of photography have been identified and the sensor and interpretation requirements are becoming increasingly well defined. At this point in time it appears that the problems related to ocean photography which have occupied SPOC research in the past are well on the way to being resolved. The first high resolution film camera designed specifically for Earth resources studies is scheduled to fly on Skylab in 1972. Short-range investigations necessary to utilize the data obtained from Skylab and to define required improvements in instruments and techniques will no doubt arise over the next few years.

There are, however, two major problems associated with the use of cameras in spacecraft which must be solved if cameras are to be used operationally, as opposed to experimentally, for oceanographic applications. These problems are:

1. Cameras require film which in any substantial amount is quite heavy and in turn requires a mechanism to return it to the ground. This implies manned return, or even less practical, as far as operational systems are concerned, capsule ejection. In either case the amount of film which can be handled is still limited.

2. Once the film has been returned to Earth automatic processing becomes a rather complex and difficult procedure, especially when compared to other forms of direct data return.

Because oceanographic applications often require coverage of a substantial portion of the Earth's surface and/or repetitive coverage at many different points in time, the above problems place substantial limitations on photography as an operational tool for spacecraft sensing.

A primary long-range research need at the present time therefore is to investigate means other than film for recording and transmitting to the ground photographic information and to support the development of automatic and accurate processing of photographic data for oceanographic purposes. Until these problems are solved, cameras may be relegated primarily to aircraft use for coastal areas or for experimental and semi-operational use from a manned space station.

Infrared radiometry for sea surface temperature and heat exchange studies has been actively studied. This is no doubt due, at least in part, to the successful use of IR radiometers on meteorological satellites and their verified application for the measurement of sea surface temperature. This success has led to significant studies to expand and optimize the use of IR data for ocean applications. As indicated in Table 8-1, SPOC has funded a number of studies which have contributed to perfection of this technique. The infrared radiometer is relatively light and its data can be transmitted by radio link digitally for rapid ground processing. At the present time the primary problems with the further development of IR radiometers for oceanography is the need for

better spatial resolution and for a means of identifying or accounting for the effects of cirrus clouds.

The third area in which SPOC has expended considerable effort has been in relation to the use of microwave radiometry and radar scatterometry for determination of sea state. The perfection of instruments and understanding of the nature of the return from them and its interpretation continues to need further study. Efforts to obtain additional understanding of the meaning of the signals through comparisons with ground truth need, in particular, to be pursued.

Because of the many groups involved, SPOC, NASA, Navy, ESSA, BCF, etc., extensive coordination has been required to insure that the total spacecraft oceanography effort is efficiently and effectively run and that duplication is minimized. This coordination has caused meetings and conferences to be held, both on a program planning level and on the scientific level. These scientific meetings, for example, provide a medium whereby investigators working in similar areas but under different sponsors can discuss experimental results and coordinate future efforts. Such a meeting was the NASA/Navy Review of Microwave Observations of the Ocean Surface (118), sponsored by SPOC in June of 1969. This meeting brought together a number of scientists working for or on contract to SPOC, NRL, and NASA to discuss present status and future directions of microwave and radar research.

Finally, in the area of spectrometry, SPOC has funded efforts aimed at the detection of chlorophyll in sea water, identification and detection of schooling fish through detection of their spectral reflectance, and the detection of fish oil slicks by analysis of their spectral reflectance.

In the following paragraphs we indicate some possible additional areas of study which SPOC might pursue in the future. To some extent these might be considered as deficiencies in SPOC's present efforts. However, it must be borne in mind that funding limitations are always present which permit only a specific subset of all possible activities to be pursued. Also in looking toward future research SPOC will want to continue to consider the efforts of other agencies and prevent duplication. For example, in the infrared sensing area, NASA/GSFC and ESSA have both been studying the technique for ocean applications. In the case of passive and active microwave techniques, because of

their potential for sea state measurements, the Naval Research Laboratory has been very active.

One of the remote sensing techniques that exhibits significant potential for ocean studies, but has not been studied to any great extent by SPOC, is the multispectral scanning technique. The only study funded by SPOC, that was reviewed, was a University of Michigan study using their multispectral scanner for water depth determination. Since a multispectral scanner (MSS) will fly on ERTS, as well as Skylab, the technique should be studied in detail from aircraft to determine its potential for ocean applications. In addition, a scanner when compared with a vidicon, which is the other imaging instrument to be flown in ERTS, can provide higher spatial as well as spectral resolution with the information output, after data reduction, being superior to that of a vidicon camera.

The lack of studies of this technique, for ocean applications, appears to carry over to other funding agencies also. In fact, the only instrument that we found to be utilized in any study was the Michigan scanner. It was true, however, that instruments utilizing the scanning technique, but in a restricted way, have been tested. For example, the NASA/MSC aircraft program employs various IR scanners. Our questionnaire also identified a number of companies that build such instruments. Phenomena that appear amenable to MSS techniques are ocean currents, color, sea ice, pollution, etc.

Another apparent deficiency that appears from examining Table 8-1 relates to studies of the use of TV imagery. This lack of research on the part of SPOC is justified, however, since many studies have been conducted by other agencies using TV imagery from the meteorological satellites. Thus, it is believed that additional studies at this time are not required.

Further examination of Table 8-1 reveals that there are certain applications areas in which SPOC has interests where little work has been undertaken by SPOC. These areas are discussed in the succeeding paragraphs.

a. Icebergs

SPOC has not sponsored any projects specifically concerned with the detection of icebergs. This is understandable as the U.S. Coast Guard, which

has the responsibility for iceberg detection and tracking, is providing research in this area. Continuous liaison is maintained between the two organizations and duplication of effort is avoided.

b. Salinity

Under contract to SPOC, Texas A&M (92) conducted a theoretical study of the feasibility of measuring the salinity of ocean water. Their conclusions were that it may be feasible, utilizing microwave radiometry, for estuaries and near shore areas where significant variations in salinity concentrations may occur. However, no actual experiment has been conducted under the sponsorship of SPOC. This is a potentially useful area which might be continued on a long-term basis.

c. Ocean Topography

Two SPOC contracts, one with New York University (67), and another with the University of Kansas (39) have investigated the feasibility of determining ocean topography, geoid, mean sea level, sea slope, and storm surges/tsunamis utilizing radar altimetry. The conclusions are that it is feasible if high resolutions can be achieved with the exception of storm surges and tsunamis which because of their nature probably would not be detected in sufficient time to be useful. No actual experiments have been conducted in this area by SPOC. Since NASA is funding studies of satellite altimeters by several other groups and has under way the GEOS-C satellite which will carry a radar altimeter, there appears to be no need for SPOC to pursue this area.

d. Pollution

SPOC has sponsored only four investigations concerned with the remote detection of pollution. A number of other groups have been active in this area, and it appears that certain pollutants in coastal areas could be detected with various techniques. However, it is believed that increased effort in this area by SPOC is desirable.

Table 8-2; Investigations Sponsored in SPOC Tabulated by Phenomena vs. User Community, and Table 8-3, Investigations Sponsored by SPOC Tabulated by User Community vs. Sensor, show how the various research efforts relate to the oceanographic user community. These matrices provide an easy reference to determine the sensors that have been used to collect data for the

various user groups. Examination of these two tables reveals the majority of the SPOC effort relates primarily to the scientific and cultural area.

As the remote sensing of oceanic phenomena is an entirely new method of collecting oceanographic data, it is understandable that the initial effort would be devoted to research and the collection of scientific information. It is first necessary to determine the capability of the remote sensors to collect data that can be meaningfully analyzed and interpreted, then decisions can be made as to the most likely areas to exploit. Once this has been accomplished it will be possible to determine who can use the data and whether the benefits derived justify the collection effort.

From the above discussion it appears that future SPOC efforts should include more pollution studies and salinity studies. Also, additional studies should be funded related to multispectral scanner techniques. Possibly the potential of color TV should be considered. In regard to areas presently being studied it is felt that a decreased emphasis on photography might be desirable except for the study of the long-term possibility of solving present problems associated with the necessity to return film and the problems associated with the lack of automated interpretation techniques.

There exists one final area which SPOC might well pursue since it was apparent from the study the area needs consideration. This is the general problem of how data might be transmitted, processed, formatted and made available to users in a meaningful way. It would appear that very little has been done on the specifics of this problem in relation to remotely sensed oceanographic data. No one interviewed, be he user, scientist, or spacecraft oriented individual seemed to have any clear idea of how the data would or should be handled once it has been sensed and transmitted to the ground. If this question is not answered well before operational data is available, it will be the limiting factor to practical application of the data.

8.2 SUMMARY AND CONCLUSIONS

8.2.1 Identification of User Community and Their Information Needs

The documents reviewed provided a good source of information for identification of the user community, however, the determination of their information needs in terms of phenomena/parameters was more difficult. Few instances were found where explicit needs were defined within the literature provided for the study. As a consequence, many of the information needs were identified through personal interviews and questionnaires. Others were deduced from inferences contained in the reports.

There is a wide diversification of user interests that require oceanographic information. Only those parameters that can either theoretically or in actual fact be measured through the use of remote sensing techniques have been considered. Potential users are found within Government (Federal, state, and local), industry, and research institutions. Use/Applications, as previously identified, are marine transportation, fishing, industry, mapping/hydrography, weather forecasting, and scientific/culture. It is suggested that additional potential users within these groups both scientific and applied, should be educated in the use of remotely acquired data, so that the potential benefits of such data might be realized.

8.2.2 User Oceanographic Requirements

All marine related activities, surface, subsurface, and above surface, impose requirements for information and knowledge of the ocean and the sea/air interface. Each activity has its own specific information requirements which in some cases are comparable with requirements of other activities (see Tables 3-1 through 3-6). The compilation of user requirements in this format should expedite certain requirements analyses for determining those needs that are applicable for space and/or airborne acquisition. Preliminary observations indicated that many requirements for similar types of data vary according to the geographical area. In fact, it appears that two separate oceanographic space systems may be advisable for total ocean survey. One for open ocean coverage and a separate one for coastal areas, which usually

require higher resolution data more frequently. Within each geographical area there are frequently a range in the requirements as specified by the potential users. This implies that if any part of the range can be met, a certain percentage of the requirements can be achieved by the system under consideration.

It is suggested by CSC that in-depth studies should be performed in each of the six use/application areas, as described in Table 2-2, to determine precisely and accurately ocean community user requirements for data that may be acquired by the use of airborne or spaceborne sensors.

8.2.3 Significant Achievements in Remote Sensing of the Ocean

Under the auspices of SPOC, NASA, other governmental agencies, and private industry, extensive research has been conducted in: (1) using off-the-shelf equipment to acquire oceanographic data, (2) developing new instruments and techniques to acquire such data, and (3) reducing and interpreting data for marine studies. SPOC, under its charter, has been especially active in sponsoring those activities concerned with developing new data acquisition techniques and analyzing data to determine its usefulness for better understanding ocean phenomena.

Since the formation of SPOC, in 1965, substantial progress has been made in remote sensing of oceanographic parameters. Research has covered a number of technical areas, including: image enhancement techniques, selecting optimum frequencies and spectrums for acquiring data, comparing of sensor returns with surface truth data, developing new instrument techniques, evaluating data for information content, and many more.

Specific results and progress are:

1. The successful detection of chlorophyll has been accomplished from low altitudes using spectroscopic methods.

2. Oil slicks have been successfully measured from aircraft altitudes using thermal IR imaging techniques. This technique shows the most potential for providing such information.

3. Nimbus HRIR data analyses have provided sea surface temperature (SST) information with fairly high resolution; however, it is not high enough to meet most oceanographic requirements. Improved resolution and accuracy could be provided with a radiometer designed expressly for SST determination.

4. Preliminary research aimed at determining the feasibility of microwave techniques for obtaining sea surface temperature has shown that additional studies are required before the technique is fully developed.

5. Preliminary radar observations of ocean backscatter have shown an increase in off-vertical backscatter with increasing sea state. It has been demonstrated that wind speed is the dominant factor in determining this return.

6. Preliminary results of microwave tests to determine sea state indicate that sea surface emission corresponds to wave heights up to at least 6 meters.

7. Ocean currents have been identified using Nimbus HRIR and ATS TV data.

8. Significant positive results have been obtained employing a variety of remote sensing techniques for the detection of sea ice. Included are radar imagery and scatterometry, multispectral scanning, laser profiling, IR radiometry and microwave imaging.

9. The use of a specially designed IR radiometer for determining heat flow from the sea surface appears to be limited to low altitude aircraft flights because of atmospheric interference. The use of microwave techniques requires a significant increase in state of the art.

10. Water depths up to 45 m have been obtained using color photography. Pulse laser systems flown in aircraft have also shown a significant potential for determining water depth in shallow areas $\approx$ 100 meters.

8.2.4 Status of Remote Sensing of Oceanographic Parameters

The current status of remote sensing techniques for ocean applications is detailed in Tables 5-1 and 5-2. Certain spacecraft instruments are feasible, using current techniques, to provide useful data for oceanography. These are:

1. IR Radiometer,

2. Television Camera,

3. Multispectral Scanner, and

4. Multispectral Camera.

Most of the initial data obtained would be of experimental nature. These and several additional sensors, as specified in Table 5-1, are also capable of providing data from aircraft for a wide range of applications.

Specific conclusions and/or recommendations are:

1. Sensor development is, in general, more advanced than the ability to accurately determine the meaning of the data and how it relates to the ocean parameters under observation.

2. All experimental data acquisition programs should include simultaneous surface truth data.

3. The optimum bands within the visible and near-IR spectrum need to be determined precisely for acquiring maximum ocean data.

4. The atmospheric attenuation occurring in various bands of the electromagnetic spectrum must be better understood in order to determine its degrading effect on the data and subsequently how it can best be removed.

5. The acquisition and subsequent interpretation of remotely acquired data for experimental purposes should be a continuing program. These processes should be constantly updated and refined with the objective of increasing the information content, determining new applications, and studying how the information relates to oceanic phenomena.

In conclusion, it appears that increased emphasis should be placed on the acquisition of test data, supplemented with concurrent and accurate surface truth data. Extensive data analysis is needed to determine how remotely sensed data can be used most efficiently and effectively to gain a better understanding of the marine environment.

8.2.5 Data Storage, Transmission and Processing

Other than the National Academy of Sciences study (78, 79), the remainder of the reports, questionnaires and interviews provided little information on requirements for data storage, transmission and processing. Our investigations indicate that individuals of the scientific and user communities have not determined their experimental data requirements, much less their operational data requirements. We believe that when specified experiments are designed, the number of data points and geographical coverage requirements will be specified, and then the amount of data to be acquired can be calculated. Using this information, trade-off studies will be required to determine the most effective mix of onboard storage and processing vs. direct transmission of raw data for ground processing. Requirements for data-receiving centers, data processing and analysis centers will then follow.

Specific conclusions of our investigations are:

1. Little progress has been made in the area of determining the data storage, transmission and processing requirements for oceanographic data.

2. The concepts developed by the NAS studies would probably satisfy the requirements of the oceanographic community.

3. R&D efforts should be initiated, by the cognizant agency, toward developing more reliable and efficient data storage devices, transmission systems, processing systems, etc. It is believed that this problem is not within the scope of SPOC's activities.

8.2.6 Benefits

It is concluded that at this time there is insufficient information to quantify the economic benefits of acquiring oceanographic data from space. The experts working in the field, for example, realize that sea surface temperature, salinity and chlorophyll do have a direct relationship with fish population. However, the state of the art of predicting what combination of these will insure the location of fish and the capabilities of remote sensors to collect data which will define these conditions is still too uncertain to determine benefits with any assurance. Likewise, the marine transportation industry

recognizes that weather routing produces savings both in transit time and ship and cargo damage. However, they do not know how much improvement space collected data will make to current weather predictions and therefore, cannot, with any certainty, quantify the benefits that would accrue.

It therefore appears that a specific estimate of benefits that might accrue from satellite collected oceanographic data is impractical and not possible at this time. To justify this program, with its potential impact, as indicated in this document, it is inappropriate to require delineation of precise costs and benefits as a prerequisite to proceed with the experimental satellite phase. The objective of an experimental phase is to precisely determine the feasibility of employing satellite technology for providing useful information to the oceanographic user community. Additional cost/benefit studies conducted prior to this phase would require an extensive number of estimates and assumptions pertaining to: data handling facilities and procedures, relevancy of data to the user, involvement of foreign countries and the implications of acquiring global data, spacecraft and instrument technology, financial support, and many more. Following the experimental stage, i.e., ERTS A and B, E and F, and Skylab, when results have been studied and evaluated so it is fairly certain what information can be acquired from space, a positive and verified cost to benefit ratio should be evident before proceeding with the operational phase.

APPENDIX A

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APPENDIX B

DETAILED STUDY PLAN

SPACECRAFT OCEANOGRAPHY DOCUMENTATION PROJECT

Contract No. N62306-70-C-0149

1.0 INTRODUCTION

The work to be accomplished for the U.S. Naval Oceanographic Office Spacecraft Oceanography Project (SPOC Project) has two objectives. The first of these is to review, compile and document the efforts of SPOC through June 30, 1969 and to report thereon. The second objective is the delineation of users, user requirements and their benefits through the remote sensing of oceanographic parameters.

2.0 STUDY PLAN

In order to perform the work required under this contract, the effort has been divided into four major tasks. These are listed below and discussed in the subsequent paragraphs.

a) Preliminary review of documents

b) 1. Review, compile, and document SPOC reports; and
   2. Evaluate, update and verify report results

c) Prepare detailed compilation of draft of report

d) Prepare final report and publish

2.1 TASK 1 - PRELIMINARY REVIEW OF DOCUMENTS

The initial review of SPOC documents will be made with three objectives in mind; these are:

a) preparation of a detailed study plan;

b) preparation of a document review form; and

c) preparation of the final report outline.

The preliminary review will be made by at least three members of the technical staff, including the project manager. Each reviewer will respond to the three objectives delineated above by developing outlines of the required responses. The project manager will review and discuss

the inputs and then synthesize final documents to satisfy the three objectives. All documents will be submitted to SPOC for review and approval.

2.2 TASK 2

Task 2 is divided into two parts: the internal documentation of the SPOC reports and the external verification of the results. These tasks are discussed below.

2.2.1 Task 2a - Review, Compile and Document SPOC Reports

At least two members of the technical staff will review each of the documents provided by SPOC. A document review form will be prepared by each reviewer. Subsequently, the reviews will be compared and the results transferred to correlation matrices (shown in the Geonautics' proposal) in order to identify the following categories of data:

a. the user community;
b. user requirements;
c. ocean phenomena to be investigated;
d. ocean parameters associated with these phenomena
e. spatial and parametric resolution;
f. measurement frequency;
g. sensor availability and sensor state of the art
h. data form, integration and transmission;
i. data processing; and
j. benefits determined

The matrices will be reviewed and duplication eliminated. The review will lead to the next task in that sources of information and questions concerning requirements and technology will be identified. These inputs are essential to the evaluation and verification of the reports which have been reviewed.

2.2.2 Task 2b - Evaluate and Verify Report Results

Based upon the review of reports accomplished in Task 2a, questionnaires will be prepared for the user community, scientific community and sensor developers. The results of initial personal interviews will generate

a feed back to further clarify the questionnaires. Finally, via the use of questionnaires and by personal interviews with the most important sources of information, the results of Task 2a will be updated, verified and documented.

The second part of this task is the identification and quantification (where possible) of the benefits which are properly assigned to spacecraft oceanography. Special emphasis will be placed upon this feature of both the questionnaires and the personal interviews.

Finally, at the completion of this task it will be possible to compare user requirements and sensor capabilities and thereby establish a current base of the state of the art. This and the other elements discussed above will be reported in the second progress report.

2.3 TASK 3 - PREPARE DRAFT OF FINAL REPORT

The draft of the final report will be prepared in accordance with the report outline. The outline represents an integrated approach in which the user community and their requirements are identified as are the means of fulfilling those requirements. The degree to which the requirements are satisfied represents, in some measure, the benefits which accrue to the system.

The draft report will be submitted for SPOC/NASA review and comments.

2.4 TASK 4 - PREPARE FINAL REPORT AND PUBLISH

All comments will be carefully reviewed and incorporated in the final report. The required number will be published and submitted to SPOC.

APPENDIX C
DOCUMENT REVIEW FORM

Title:

Author(s):

Organization (Agency, Institution, Company):

Date:

Sponsoring Agency:

Type of Report:

User(s) identified (explicit or implicit):

User(s) requirements identified (explicit or implicit):

Platform used:

Buoy-ship-pier-tower
Aircraft
Space-craft

Instrument tested:

Phenomena sensed:

Location
Number of times

Long-term objectives:

Short-term objectives:

Title:

Author(s):

Enhancement of Oceanic (Uses) / Ocean Phenomena	Resources Exploitation & Utilization	Transportation & Commerce	Commercial Fisheries	Recreation	Coastal Zone	Hydrography-Mapping	Pollution Control	Ecological & Biological Studies	
Color									
Sea Ice									
Surface Roughness									
Surface Temperature									
Biology									
Cloud Cover									
Coastal Mapping									
Coastal Processes									
Currents									
Ecology									
Hydrography-Bathymetry									

Title:

Author(s):

Ocean Phenomena / Ocean Parameters	Color	Sea Ice	Sea Roughness	Surface Temperature	Biology	Coastal Mapping	Coastal Processes	Currents	Ecology	Fishing	Heat Exchange	Hydrography			
Temperature AC															
OF															
R															
Wave Height AC															
OF															
R															
Wave Period AC															
OF															
R															
Wave Direction AC															
OF															
R															
Current Velocity															
Current Direction															
Wind Direction															
Wind Velocity															
Cloud Cover															
Color															
Water Depth															

AC - Aerial Coverage
OF - Observational Frequency
R - Resolution

Title:

Author(s):

Sensor / Ocean Parameter	Visible Spectrum (active/passive)						Infra-red	Microwave (active/passive)				
	Photo B&W	Photo Color	Multispectral	Television	Spectrophotometer	Laser	Radiometer	Radiometer	Radar (various bands)	Imaging Radar	Radar Altimeter	Scatterometer
Temperature a) b)												
Wave Height												
Wave Period												
Wave Direction												
Current Velocity												
Current Direction												
Wind Velocity												
Wind Direction												
Cloud Cover												
Color												
Water Depth												
Stage of Development												

Title:

Author(s):

Data Requirements

Data collection:

Data storage:

Data manipulation (averaging) on board:

Data transmission:

Data handling:

Data analysis:

Timing:

Data output:

IRLS system:

Title:

Author(s):

System Economics

Benefits:

APPENDIX D
QUESTIONNAIRE TO OBTAIN USER REQUIREMENTS FOR OCEANOGRAPHIC DATA

This questionnaire was developed for the purpose of obtaining information to assist the U. S. Government in planning for and implementing a program to acquire oceanographic data using air and space borne remote sensors. We request from you, as a representative of a specific user of oceanographic data, certain information to assist us in determining user requirements. The questionnaire, for convenience, has been divided into three groups.

These groups are:

1. Oceanographic information you presently utilize in your organization's operations.
2. Oceanographic data you could presently utilize, if it were available, to meet current needs.
3. Requirements for oceanographic data you can see a need for in the near future.

Types of information we refer to are, for example, surface temperature, temperature profile, salinity, wave height, wind speed, chlorophyll content, oil pollution, water depth, water color, sea ice, etc.

Date ____________________

Name and title of person completing questionnaire:

____

____ Telephone ______________________

Name and address of organization:

____

____

____

Nature of your company's operations, such as,

(check those applicable)

a. Marine Transportation ______ b. Offshore Oil Exploration ______

c. Offshore Mineral Exploration ______ d. Fishing ______

e. ______________________________
(Other - Specify)

f. ______________________________

g. ______________________________

h. ______________________________

Identify in the space provided, a single type of oceanographic data you either presently utilize or could utilize, if available, in your operations.

Information utilized: ____
(such as surface temperature, surface roughness, etc.)

Please complete the remainder of this questionnaire relative to that parameter you have specified above. If other information is used or required by your company, please complete an additional questionnaire for each type.

1. Specify the organization(s) such as Federal or State Agencies or private groups, that presently supply the information you use.

	Organization	Type of Data	Format of Received Data and Mode of Distribution
Example	Tuna Resources Lab.	Sea surface temp.	Temperature map received by mail
	a.		
	b.		
	c.		

2. Does the information received meet your minimum requirements for this type of data? ______________
yes/no

3. Does the information received meet all your requirements for this type of data? ______________
yes/no

4. Please describe the data you now receive relative to the following questions, if applicable.

What is the:

a. Geographic area of coverage?	
b. Form in which data are received?	
c. Time of year or season for which information is received?	
d. Frequency with which data are received?	
e. Accuracy of data?	
f. Timeliness of data	
g. ______________ (other - specify)	
h.	

5. If current data are not satisfactory, indicate your present requirements.

a. Geographic area of coverage	
b. Preferred form to receive data	
c. Time of year or season information is required	
d. Frequency with which data are required	
e. Accuracy of data required	
f. Timeliness of data	
g. ______ (other - specify)	
h.	

6. If you can foresee a change in your particular needs in the near future (1980), please indicate your requirements.

a. Geographic area of coverage	
b. Preferred form to receive data	
c. Time of year or season information is required	
d. How often information is required	
e. Accuracy required	
f. Timeliness of data	
g. ______ (other - specify)	
h.	

Comments:

Date ______________

APPENDIX E
QUESTIONNAIRE TO OBTAIN USER OCEANOGRAPHIC DATA REQUIREMENTS AND REMOTE SENSOR STATE OF THE ART

This questionnaire was developed for the purpose of obtaining information to assist NASA and NAVOCEANO in planning for and implementing a program to acquire oceanographic data using air and space borne remote sensors. It is addressed to those persons who research and design and/or operate systems for acquiring oceanographic data to meet the needs of users. Because of the many aspects of remote sensing of oceanographic phenomena the questionnaire, of necessity, is more voluminous than we would like. We are asking you to complete only those portions of the questionnaire in which you have direct interest and/or experience. For those questions that do not apply to your field, please indicate by "N/A".

Name and title of person completing questionnaire

____

________________________________ Telephone ____________________

Name and address of organization with which you are affiliated

____

____

____

Nature of your organization's interest (application). Check if applicable.

a. Determination of sea state -
b. Location of fish -
c. Weather prediction -
d. Hydrographic surveying -
e. Coastal Management -
f. Improving the understanding of the marine environment -
g. ________________________ (other - specify)
h.
i.

Please specify your area of expertise ________________________________.

Are you concerned with presently operating systems ____________________ (specify) and/or future systems __________________ (specify). Have you been active in the area of remote sensing of Earth resources __________________ (yes/no).

USER DATA REQUIREMENTS AND STATUS
OF PRESENT DATA COLLECTION SYSTEMS

A. DATA ACQUISITION

1. Please specify below those oceanographic parameters you currently acquire data on, either to meet the needs of users or for research purposes, such as surface temperature, sea state, water depth, etc., and identify the use (application) to which they are or could be applied such as resource exploration, marine transportation, fish location, etc. All identical letters in subsequent questions of this section relate to the parameters specified in this question. If more space is needed use additional sheets of paper identifying each statement by the appropriate number and letter combination.

	Parameter	Use	
Example	Surface temperature	fish location	pollution control
	a.	a.	
	b.	b.	
	c.	c.	

2. What method is presently used to acquire the data, and is the method satisfactory?

	Ship	Buoy	Space-craft	Air-craft	Other (Identify)	Agency Acquiring Data	Sat	Un-sat
a.								
b.								
c.								

If unsatisfactory, indicate deficiency

a.

b.

c.

3.1 What geographic area is covered by the data presently obtained? Specify.

	Sat	Un-sat
a.		
b.		
c.		

3.2 If the coverage of 3.1 is unsatisfactory, what geographical area coverage is required to meet present minimum requirements?

a.

b.

c.

3.3 What geographical area coverage is needed to meet requirements during the 1980 time frame?

a.

b.

c.

4.1 What number of data points are presently acquired over a specific area (5 per km^2, 5 per 100 km^2, etc)?

	Sat	Un-sat
a.		
b.		
c.		

4.2 If number of data points in 4.1 are unsatisfactory, what number do you require to meet present minimum user requirements?

a.

b.

c.

4.3 What number of data points would you specify to meet user requirements during the 1980 time frame?

a.

b.

c.

5.1 In what time frame and with what frequency are basic data currently acquired?

	Time Frame (continuous, seasonal, etc.)	Sat	Un-sat	Frequency (once a day, once a week, etc.)	Sat	Un-sat
a.						
b.						
c.						

5.2 If specifications outlined in 5.1 above are unsatisfactory, what time frame and frequency for data acquisiton are required to meet present minimum requirements?

a. a.

b. b.

c. c.

5.3 What time frame and what frequency do you foresee as meeting user requirements in the 1980 time frame?

a. a.

b. b.

c. c.

B. <u>DATA HANDLING</u>

Note: All the a's, b's, and c's continue to relate back to the first question of Section A.

1.1 In what format (chart, digital, analog, photo, etc.) is basic data received and is transmission delayed or in real time?

Format	Sat	Un-sat	Real Time	Delayed	Sat	Un-sat
a.						
b.						
c.						

1.2 If the present method is unsatisfactory or if a requirement exists to receive such data and it is not being fulfilled, please indicate format and mode of transmission (real time or delayed) that is required.

Format	Real Time	Delayed
a.		
b.		
c.		

1.3 If you expect a requirement for this type of basic oceanographic data to exist during the 1980 time frame, specify format and the mode of transmission you feel will be necessary.

Format	Real Time	Delayed
a.		
b.		
c.		

2.1 In what format is reduced data currently disseminated (chart, map, photograph, analog or digital, etc.)? Specify.

	Sat	Un-sat
a.		
b.		
c.		

2.2 If present format is unsatisfactory, what format is required to meet present minimum requirements?

a.

b.

c.

2.3 What format will be required to meet user requirements during the 1980 time frame?

a.

b.

c.

3.1 In what mode, such as radio, mail, teletype, etc., and with what frequency is updated information delivered to the user?

Mode	Sat	Un-sat	Frequency	Sat	Un-sat
a.					
b.					
c.					

3.2 If present mode and/or frequency is unsatisfactory, what are the user requirements to meet present minimum standards?

Mode	Frequency
a.	a.
b.	b.
c.	c.

3.3 In what mode and with what frequency will updated information be required to meet user requirements in the 1980 time frame?

Mode	Frequency
a.	a.
b.	b.
c.	c.

4.1 What is the resolution of data presently received by the ultimate user (such as fishermen, marine shippers, marine biologists, etc.)?

RESOLUTION

Spatial*	Sat	Un-sat	Spectral*	Sat	Un-sat	Temperature*	Sat	Un-sat
a.								
b.								
c.								

*Spatial - Side dimension in meters of resolvable objects
Spectral - Smallest portion of the resolvable spectrum, in microns
Temperature - Absolute surface temperature in degrees Kelvin

4.2 If presently obtained resolution is unsatisfactory, what resolution is required to meet current minimum requirements?

RESOLUTION

	Spatial	Spectral	Temperature
a.			
b.			
c.			

4.3 What resolution is required to meet user requirements of the 1980 time frame?

RESOLUTION

	Spatial	Spectral	Temperature
a.			
b.			
c.			

5. If your organization acquires and/or distributes any of the above data, who specifies the requirements?

a.

b.

c.

6. Is there any cost to the user for data you distribute? Specify

a.

b.

c.

0

C. EXPERIMENTS CONDUCTED TO DATE

Complete the following matrix for those parameters you have studied either as an investigator of a specific aircraft or spacecraft borne sensing experiment, or as a member of a data analysis team analyzing data from remote sensing experiments of the ocean environment. If more room is required please use additional pages and identify by parameter letter and box number.

Parameter 1	Platforms Utilized & Alt. Flown 2	Remote Sensors Utilized 3	Ancillary Sensors Utilized 4	Geographic Location & Date of Test 5	Resolution Achieved			Funding Organization 7
					Spatial*	Spectral**	^{o}K 6	
A								
B								
C								
D								
E								

* Spatial - meters on a side
** Spectral - Micron (u)

Significant results and other comments (objectives, history, etc.)

D. STATUS OF DATA REDUCTION AND INTERPRETATION TECHNIQUES

Are ground techniques (not volume of equipment) adequate for handling and analyzing presently acquired spacecraft and aircraft data? Where problem areas exist, specify.

Are ground techniques satisfactory for:	PROBLEM AREAS (Explain)						
	Reduction	Yes / No	Interpretation	Yes / No	Dissemination	Yes / No	Other Comments
Photographic Data							
Infrared Data							
Microwave Data							
Radar Data							
(Other - specify)							

Please indicate below specific areas of development you feel are required in order to achieve an operational capability to process spacecraft acquired data accurately and efficiently. Use additional pages if necessary.

1.

2.

3.

4.

E. POTENTIAL SPACE APPLICATIONS

Some spacecraft data acquisition programs presently do or could in the near future contribute to the measurement of certain oceanographic parameters List below those parameters you have studied or have specific interest in and check appropriate boxes.

Parameter	Capable of Contributing							
	Not at all		Slightly		Extensively		Satisfy Completely	
	Now	Future	Now	Future	Now	Future	Now	Future

Comments:

F. BENEFITS FROM SPACE ACQUIRED DATA

For each user category you are involved with or have an interest in, please complete the following matrix relative to benefits you feel are achievable in the near future, utilizing data acquired from space borne instruments.

Parameter	Sector Concerned		Application of Space Derived Information	Benefits from Space Derived Data (check appropriate box)			Comments
	Govt.	Private		Eco-nomic	Support Nat'l Policy	Scien-tific	

Comments:

Note: If economic benefits accrue, please indicate a dollar amount, if possible and briefly describe method of computation.

APPENDIX F

QUESTIONNAIRE TO OBTAIN STATE OF THE ART INFORMATION ON REMOTE SENSOR DEVELOPMENT

This questionnaire was developed for the purpose of obtaining information to assist NASA and NAVOCEANO in planning for and implementing a program to acquire oceanographic data using air and space borne remote sensors. We request from you, as a representative of a concern active in remote sensor development, certain information to assist us in determining state of the art in instrument development.

Date ________________

Name and title of person completing questionnaire

____

______________________________ Telephone ________________

Name and address of organization with which you are affiliated

____

____

____

Instrument areas you or your organization specializes in - please specify

a. Photographic - __________

b. Television - __________

c. Infrared - __________

d. Microwave - __________

e. Radar - __________

f. ____________________
(other - specify)

g. ____________________

h. ____________________

A. INSTRUMENT STATE OF THE ART

Please complete this section relative to those instruments in which you or your organization have experience. Include only those that have application to the remote sensing of oceanographic parameters, either from aircraft and/or spacecraft. If state of the art is classified, please so state and complete using unclassified data, if possible. All identical letters in this section relate to the instrument originally specified in question No. 1 below. If more room is required please add additional pages.

1. Name sensor and describe

   a.

   b.

   c.

2. Parameters to be measured by instrument

   a.

   b.

   c.

3. Spectral range of instrument

   a.

   b.

   c.

4. Field of view of instrument

   a.

   b.

   c.

A. INSTRUMENT STATE OF THE ART (Continued)

5. Resolution achievable if instrument is or were to be built now, specify the altitude used in your calculation, such as: (20 m from 125 n. mi. alt.)

Spatial (meters)	Spectral (u)	Temperature (^{o}K)

a.

b.

c.

6. Resolution predicted for 1980 time frame, specify the altitude used in your calculation

Spatial (meters)	Spectral (u)	Temperature (^{o}K)

a.

b.

c.

7. Is instrument/technique applicable for space deployment? Take into consideration weight, power, and volume requirements and its potential applications.

a.

b.

c.

8. Output format, such as analog, digital, chart, photograph, etc.

a.

b.

c.

A. INSTRUMENT STATE OF THE ART (Continued)

9. Estimated Data Rate (in bits/sec), if applicable

	Presently	1980
a.		
b.		
c.		

10. Is instrument scheduled to be flown in aircraft or spacecraft in the near future - explain?

a.

b.

c.

11. Status of present instrument development

a.

b.

c.

12. Year instrument could be available for spacecraft deployment (if go-ahead for development were given in FY 1971)

a.

b.

c.

13. Specify additional areas of research and development, relative to your area of expertise, you feel are required to achieve an operational capability for remote sensing of the oceans from space vehicles.

a.

b.

c.

B. INSTRUMENT/TECHNIQUE - DEVELOPMENTAL PROGRESS

Please complete the following matrix relating to progress in the state of the art of the instrument areas you have been involved with or have an interes in. If possible indicate date, otherwise, check.

Aircraft Instrumentation

Oceanographic Parameter	Instrument (be specific) / Instrument Development Status	Operational for Aircraft	Instrument/ Technique Tested in Aircraft	Requires Additional Development	Requires Major Development	Feasibility Studies Have been Conducted	Comments

Spacecraft Instrumentation

Oceanographic Parameter	Instrument (be specific) / Instrument Development Status	S/C Hardware Developed	Not Space Qualified	Requires Additional Development	Needs Major Development	Feasibility Studies Have been Conducted	Instrument/ Technique Tested in A/C	Comments

APPENDIX G

LIST OF INDIVIDUALS AND ORGANIZATIONS RECEIVING QUESTIONNAIRES

GROUP I - COMMERCIAL USERS

Alaska Steamship Company
Skinner Building
Seattle, Washington

All American Engineering Co.
Lancaster Pike and Center Rd.
Wilmington, Del. 19899

Alpine Geophysical Associates, Inc.
65 Oak Street
Norwood, New Jersey 07648

American Export Isbrandtsen Lines
26 Broadway
New York, New York

American President Lines
20 Broadway
New York, New York

American President Lines
Finance and Control
601 California Street
San Francisco, California 94108

Aqua-Con, Inc.
221 Via Alameda
Redondo Beach, Calif. 90277

Astro Marine
518 First City National Bank Bldg.
Houston, Texas 77002

Ball Brothers Research Corp.
Box 1062, Boulder Industrial Park
Boulder, Colorado 80302

Barber Steamship Lines, Inc.
17 Battery Place
New York, New York

Bechtel Corp.
50 Beale Street
San Francisco, Calif. 94119

Bendix Corporation
Environmental Science Division
1400 Taylor Avenue
Towson, Maryland 21204

Bendix Corporation
Semiconductor Division
South Street
Holmdel, New Jersey 07733

Bendix Field Engineering Corp.
Owings Mills, Maryland 21117

Bermuda Biological Station
St. George's West
Bermuda 31440

Black Diamond Steamship Corp.
2 Broadway
New York, New York

Braincon Corporation
Subsidiary of General Time Corp.
13 Shenandoah Road
Marion, Mass. 02738

Brown & Root, Inc.
Box 3
Houston, Texas 77001

Canadian Pacific Steamships
581 Fifth Avenue
New York, New York

Century Geophysical Corporation
6540 East Apache
Tulsa, Oklahoma 74115

Chevron Oil Co.
8435 West Glen Drive
Houston, Texas

Chevron Shipping Company
555 Market Street
San Francisco, California 94105

Coast Engineering Company
711 West 21st Street
Norfolk, Virginia 23517

Coast Oyster Co.
P.O. Box 166
South Bend, Wash. 98586

Commercial Engineering Corporation
5205 Ashbrook
Houston, Texas 77036

Continental Shelf Data Systems
424 Denver Hilton Office Building
Denver, Colorado 80202

Cook Fish Company
1301 Marvin Avenue
Port St. Joe, Fla. 32456

Crawford Marine Specialists, Inc.
Piers 38-40
The Embardadero
San Francisco, Calif. 94107

CWC Fisheries, Inc.
312 Commercial Bldg.
P.O. Box 2
Ketchikan, Alaska

Dames & Moore
445 South Figueroa Street
Los Angeles, Calif. 90017

Decca Survey Systems, Inc.
3418 Mercer Street
Houston, Texas 77027

Deepsea Ventures, Inc.
Newport News, Virginia

Delta Steamship Lines, Inc.
17 Battery Place
New York, New York

Dillingham Corp.
Hydro Products Division
Box 2528
San Diego, Calif. 92112

Dillingham Corp.
Oceanographic Engineering Group
11803 Sorrento Valley Road
San Diego, Calif. 92121

Huntec Ltd.
Division of Kenting Exploration
1450 O'Connor Dr.
Toronto 16, Ont.
Canada

D&S Seafood, Inc.
P.O. Box 5765
Tampa, Fla.

Eagle Enterprises
2415 North Fairmont
Santa Ana, Calif. 92706

Esso International
New York, New York

Everingham Bros. Bait Co.
5268 Roswell St.
San Diego, Calif.

Excuision Inlet Packing Co.
P.O. Box 1211
Juneau, Alaska

Fahren Sud Line
44 Whitehall St.
New York, New York

Felicione & Sons Fish Co., Inc.
1415 Ashley St.
Tampa, Fla. 33602

Fish Meal Co.
P.O. Box 397
Moss Point, Miss.

Fishermans Packing Corp.
1208 3rd St.
Anacortes, Wash.

French Lines
17 Battery Place
New York, New York

Ft. Myers Seafood Packers, Inc.
1300 Carson St.
Fort Myers, Fla.

General Dynamics Corp.
Electronics Division
1400 North Goodman St.
Rochester, New York 14601

General Electric Company
Tempo Division
816 State Street
Santa Barbara, Calif. 93102

General Marine Transport
Breakwater
Santa Barbara, Calif. 93105

General Oceanology, Inc.
27 Moulton Street
Cambridge, Mass. 02138

GeoMetrics
914 Industrial Avenue
Palo Alto, Calif. 99303

Georex, Inc.
2920 Weslayan
Suite 203
Houston, Texas 77027

Global Marine Corp.
650 South Orand Avenue
Los Angeles, Calif. 90017

Grace Line
3 Hanover Square
New York, New York

Grace Line, Inc.
2 Pine Street
San Francisco, Calif. 94111

G. Vanderborgh & Son, Inc.
West Sayville
New York

H.M. Tiedemann Company
74 Trinity Place
New York, New York 10006

Holland-America Line
Pier 40, N.R.
New York, New York

Howard Miller
P.O. Box 1531
Tampa, Fla. 33601

International Center for Strategic Studies
4636 Vineta Avenue
La Canada, Calif. 91011

International Diving Hawaii
Industrial Inner Space Division
1249 South Beretania St.
Honolulu, Hawaii 96814

International Underwater Contractors
Bayside, Long Island
New York 11360

Isotopes, a Teledyne Company
Palo Alto Laboratory
4062 Fabian St.
Palo Alto, Calif. 94303

Italian Line
1 Whitehall Street
New York, New York

James A. Roberts Associates, Inc.
Box 4098
Irvine, Calif. 92664

John I. Thompson & Company
1118 22nd Street N.W.
Washington, D.C. 20037

J.R. Hardee Shrimp Co.
Star Route, Box 130
Brownsville, Texas

Judith Joyce
50 West 55th Street
New York, New York 10019

Kenai Salmon Packing Co.
Box 190
Kenai, Alaska 99611

Klien Associates
Route 111, RFD 2
Salem, New Hampshire 03079

Kodiak Fisheries Co.
Port Lions
Kodiak Island, Alaska 99615

Kornfeld International
Offshore Technical Services Div.
Suite 610 Mid-Continent Bldg.
Tulsa, Oklahoma 74103

Laser Systems & Electronics
Tullahoma, Tennessee

Lewis & Lewis Offshore, Inc.
Box 820
Ventura, Calif. 93001

Liberty Fish & Oyster Co.
Pier 7
P. O. Box 267
Galveston, Texas

Litton Industries
Western Geophysical Division
933 North LaBrea Avenue
Los Angeles, 90038

Lockheed Missiles & Space Co.
R&D Division
Ocean Systems
Sunnyvale, Calif. 94088

Makai Range, Inc.
Makapuu Point
Waimanalo, Hawaii 96795

Mako Products, Underwater, Inc.
2931 N. E. 2nd Avenue
Miami, Florida 33137

Marine Acoustical Services, Inc.
Subsidiary of Tracor, Inc.
1975 S. W. 14th Court,
Ft. Lauderdale, Florida 33313

Marine Advisers, Inc.
Subsidiary of Bendix Corp.
Box 1963,
La Jolla, Calif. 92037

Marine Contracting Intl., Inc.
3280 Post Road
Southport, Conn. 06490

Marine Construction & Design
2300 W. Commodore Way
Seattle, Washington 98199

Marine Electronic Equipment
Box 10212
Fort Lauderdale, Florida 33311

Marine Projects, Inc.
1818 Westlake N.
Seattle, Washington 98109

Marine Resource Consultants, Inc.
225 Santa Monica Blvd.
Santa Monica, Calif. 90265

Marine Resources, Inc.
150 Winton Road, North
Rochester, New York 14610

Marine Testing Institute, Inc.
1 Depot Plaza
Mamaroneck, New York

Matson Navigation Co.
630 Fifth Avenue
New York, New York

Matson Navigation Company
100 Mission Street
San Francisco, Calif. 94105

McAllister Equilment Leasing Co.
P. O. Box 666
Cordova, Alaska

M. J. Richardson, Inc.
2516 Via Tejon
Palos Verdes, Est., Calif.

Moore-McCormack Lines, Inc.
2 Broadway
New York , New York

Moore-McCormack Lines, Inc.
World Trade Center
San Francisco, Calif. 94111

Mystic Oceanographic Co.
Box 53
Mystic, Conn. 06355

Nakat Packing Corp.
1355 Dexter
Horton Bldg.
Seattle, Wash.

New England Fish Co.
Box 1121
Juneau, Alaska

Northwest Oceanographers, Inc.
Operations
350 South Magnolia Avenue
Long Beach, Calif. 90802

Ocean Harvest Corp.
Miami, Florida

Ocean Industries, Inc.
Portland, Oregon

Ocean Protein
P. O. Box 3636
Port Arthur, Texas 77640

Ocean Science and Engineering, Inc.
4905 Del Ray Avenue
Washington, D. C. 20014

Ocean Systems, Inc.
270 Park Avenue
New York, New York 10017

Oceaneering Services Company
Box 3298
Indialantic, Florida 32901

Oceanographic Services, Inc.
5375 Overpass Road
Santa Barbara, Calif. 93105

Oceanonics, Inc.
6204 Evergreen Street
Houston, Texas

Oceans General, Inc.
615 S. W. Second Avenue
Miami, Florida 33130

Oceans International, Inc.
Box 91
Mystic, Conn. 06355

The Offshore Corp.
3411 Richmond
Houston, Texas

Offshore Explorations Group, Inc.
2711 Timmons Lane
Houston, Texas

Offshore/Sea Development Corp.
99 Nassau Street
New York, New York 10038

Olympic Geophysical Co.
4007 Richmond Avenue
Houston, Texas

Ottis Purifoy
P. O. Box 444
Morehead City, N. C.

Pacific Coast Transport
P. O. Box 846
Wilmington, California 90746

Pacific Far East Lines
141 Battery Street
San Francisco, California 94111

Pacific Submersibles, Inc.
Aff. of Telecheck
45-015 Lilipuna Place
Kaneohe, Hawaii 96744

Pacific Weather Analysis
193 Constitution Drive
Menlo Park, Calif. 94025

Patterson Shrimp Co., Inc.
1109 Seventh St.
Franklin, La. 70538

Petr-O-Tech, Inc.
22715 Ventura,
Woodland Hills, Calif.

Petty Geophysical Engineering Co.
Box 2061
San Antonio, Texas 78206

Phoeger Packing Co.
Darien, Ga.

Western Offshore Drilling &
Exploration Company
12623 East Imperial Hwy
Santa Fe Springs, Calif. 90670

Port Fisheries, Inc.
P. O. Box 158
Port Island, Texas 78578

Precision Surveys, Inc.
Point & Erie Streets
Camden, New Jersey 08102

Ray Geophysical
6909 Southwest Freeway
Houston, Texas

RCA Service Company
Government Services
Cherry Hill Office, Bldg. 206-2
Camden, New Jersey

Reading & Bates
Ocean Engineering Division
Phiotower
Tulsa, Oklahoma 74103

Reynolds Submarine Services Corp.
1901 North Fort Myer Drive
Arlington, Va. 22209

Salvor
4040 North Rockwell Street
Chicago, Ill. 20218

Sanford Marine Services, Inc.
Subsidiary of Westinghouse Elec.
Corp.
Box 432
Morgan City, La. 90380

Santa Fe Drilling
P. O. Box 2638
Santa Fe Springs, Calif. 20670

Seafloor Contractors
3400 Grand Avenue
Neville Island
Pittsburgh, Pa. 15225

Seafood Sales Agency
P. O. Box 1069
Houma, La.

Seaforth Sportfishing Corp.
1641 Quivira Rd.
San Diego, Calif.

Sea-Land of California, Inc.
Marine Operations Pacific
1425 Maritime Street
Oakland, California

Sea Pak Corporation
St. Simmons Island, Georgia

Spence Bros. Fish Co.
P. O. Box 578
Niceville, Fla.

Standard Products Co., Inc.
Kilmarnock, Va. 22482

Star Fish & Oyster Co., Inc.
P. O. Box 26
Industrial Canal
Mobile, Ala.

Star-Kist Fishing Co.
582 Tuna St.
Terminal Island, Calif.

State Boat Corp.
3701 Kirby Drive
Houston, Texas 77006

States Marine-Isthmian Lines
New York, New York

States Steamship Corporation
320 California Street
San Francisco, California 94104

S. W. Rouzie, Inc.
5400 Sunnywood Drive
Virginia Beach, Virginia 23455

Tampa Shrimp Co., Inc.
P. O. Box 416
Fernandian Beach, Fla.

Teledyne Company
Earth Sciences
171 North Santa Anita Avenue
Pasadena, Calif. 91107

Teledyne Exploration Company
Marine Sciences Division
Box 36269
Houston, Texas 77036

Tetra Tech Inc.
La Jolla Division
7730 Herschel
La Jolla, Calif. 92037

Texaco, Inc.
New York, New York

Texas Instruments, Inc.
Science Services Division
Box 5621
Dallas, Texas 75222

Texas Menhaden Co.
P. O. Box 68
Sabine Pass, Texas 77655

Thompson Enterprises, Inc.
813 Caroline St.
Key West, Fla.

Tracor, Inc.
Hydrospace Programs Dept.
Science & Systems Division
6500 Tracor Lane
Austin, Texas 78745

Triton Eng. & Const. Ltd.
Olympic Canvas & Rope Lts.
866 Cordove St.
Vancouver, B. C.
Canada

Umar Oceanics
8367 Oso Avenue
Canoga Park, Calif. 91306

Undersea Engineering & Const. Co.
1110 University Ave., Ste. 510
Honolulu, Hawaii 96814

Undersea Television Corp. of America
1526 Aurora Avenue, North
Seattle, Washington 98109

Underwater Technics, Inc.
Box 101
Maple Glen, Pa. 19002

United Fruit Co.
Pier 2 & 3, N. R.
New York, New York

United States Lines
1 Broadway
New York, New York

Versaggi Boats, Inc.
P. O. Box 188
Patterson, La.

Washington Fish & Oyster Co.
Port Williams
Alaska 99615

Waterman of Puerto Rico-USA, Inc.
19 Rector Street
New York, New York

Western Geophysical Co.
8100 Westpark Road
Houston, Texas

Westinghouse Electric Corp.
Underseas Division
Ocean Research & Engineering
Center
Box 1488
Annapolis, Maryland 21404

Weyerhaeuser Line
141 Battery Street
San Francisco, California

Windjammer Cruises, Inc.
Box 120
Miami Beach, Florida 33139

Zapata Norness, Inc.
2000 Southwest Tower
Houston, Texas 77002

APPENDIX H

LIST OF INDIVIDUALS AND ORGANIZATIONS RECEIVING QUESTIONNAIRES

GROUP 2 - GOVERNMENT USERS AND SCIENTISTS

Alaska Dept. of Fisheries
Juneau, Alaska

Allied Research Associates
Concord, Mass.
James C. Barnes

Allied Research Associates
5809 Annapolis Rd.
Hyattsville, Md. 20784
Mr. Earl Merritt

American Tuna Boat Assoc.
San Diego, Calif. 92106
Director - August Felando

Arctic Research Lab.
Point Barrow, Alaska
Director, Max C. Brewer

Atlantic States Marine Fisheries Commission
3965 W. Pensacola St,
Tallahassee, Fa. 32304
Milton T. Hickman, Chairman

Atlantic Sea Run Salmon Comm.
University of Maine
Orono, Maine 04473
Chairman: Ronald T. Speers

Beaudette Foundation
P.O. Box 229
Moss Landing, Calif. 95039
Palmer T. Beaudette, Pres.

Bureau of Commercial Fisheries
Biological Lab.
Honolulu, Hawaii

Bureau of Commercial Fisheries
California Cooperative Fisheries Investigations
La Jolla, Calif.

Bureau of Commercial Fisheries
Exploratory Fishing and Gear Research Base
P.O. Box 1668
Juneau, Alaska

Bureau of Commercial Fisheries
Exploratory Fishing & Gear Research Base
Gloucester, Mass.

Bureau of Commercial Fisheries
Exploratory Fishing & Gear Research Station
Miami, Florida

Bureau of Commercial Fisheries
Fishery Oceanography Center
300 S. Ferry St.
Terminal Island, Calif. 90731

Bureau of Commercial Fisheries
Tropical Atlantic Biological Lab.
75 Virginia Beach Dr.
Miami, Fla. 33149
Dr. J. Frank Hebard

Bureau of Sport Fisheries & Wildlife
Sandy Hook Marine Lab.
Highlands, New Jersey 07732
Mr. Thomas R. Azorovitz

Bureau of Sport Fisheries & Wildlife
Salmon Culture Laboratory
Longview, Washington

Bureau of Sport Fisheries & Wildlife
Pascagoula, Miss.
Harvey R. Bullis, Jr., Director

Bureau of Sport Fisheries and
Wildlife
Tiburon Marine Lab.
Dept. of the Interior
P.O. Box 98
Tiburon, Calif. 94920

Bureau of Sport Fisheries &
Wildlife
Oceanographic Coordinator
Washington, D.C. 20240

Calif., Univ. of
La Jolla, Calif.
Leonard N. Liebermann

Chesapeake Biological Lab.
Univ. of Maryland
Solomons Islands, Md.

Coast & Geodetic Survey; ESSA
Rockville, Md. 20852
Vice Admiral, D.A. Jones

Coast Guard
International Ice Patrol
Woods Hole, Mass.

Coast Guard
400 7th St. S.W.
Wash., D.C. 20591
Lt. CDR McKintosh

Coastal Engineering Research Ctr.
5201 Little Falls Rd., N.W.
Washington, D.C. 20852
Dr. G.J. Galvin

ESSA
Boulder, Colorado
D.D. Crombie

Federal Water Pollution Control
Administration
633 Indiana Avenue, N.W.
Washington, D.C. 20242
Dr. Alphonse F. Forziati

Florida Commission on Marine
Sciences and Technology
95 Merrickway, Suite 715
Coral Gables, Florida 33134
Dr. F. Walton Smith

Florida Engineering and Industrial
Experiment Station
Coastal Engineering Lab.
Univ. of Florida
Gainsville, Florida 32603
Dr. Marion E. Forsman, Director

Food & Agriculture Organization
of the United Nations
Director, Fisheries Division
Roy I. Jackson

Geological Survey
1305 Tacoma Avenue
Tacoma, Washington 98412
Mr. W. T. Campbell
Water Resources Div.

Great Lakes Commission
5104 Institute of Science & Tech-
nology Bldg.
2200 North Campus Blvd.
Ann Arbor, Michigan 48105
Mr. Leonard J. Goodsell, Exec.
Director

Great Lakes Fishery Commission
1451 Green Road
Ann Arbor, Michigan 48105
Mr. Norman S. Baldwin
Exec. Director

Gulf Coast Research Lab.
Ocean Springs, Miss.
Director, Dr. Gordon Gunter

Gulf States Marine Fisheries
Commission
400 Royal St.,
New Orleans, La. 70130
Joseph V. Colson, Exec. Director

Gulf Univ. Research Corp.
College Station, Texas 77840
Dr. James M. Sharp

Harvard Univ.
Biological Labs.
16 Divinity Ave.
Cambridge, Mass. 02138
Dr. George Clarke

Hopkins Marine Station
Stanford Univ.
Pacific Grove, Calif.
Director, John C. Phillips

Humbolt State College
Arcata, Calif. 95521
Dr. Robert Thompson
Dept. of Oceanography

Institute of Oceanography and Marine Biology
Oyster Bay, Long Island
New York

International Pacific Halibut Commission
Seattle, Washington

John Hopkins Univ.
Chesapeake Bay Inst.
Baltimore, Md. 21218

Joint Tsunami Research Effort
ESSA
Honolulu, Hawaii

Mackay School of Mines
Univ. of Nevada
Reno, Nevada
Joseph Lintz, Jr.

Maine-Dept. of Sea and Shore Fisheries
Augusta, Maine
S. Apollonis, Director

Maritime Commission
Washington, D. C.
E. Kemper Sullivan
Chief of R&D

Michigan, Univ. of
Great Lakes Research Div.
Inst. of Science & Technology
Ann Arbor, Mich.
Attn: Dr. John C. Ayers

Michigan, Univ. of
Willow Run Labs.
Ann Arbor, Mich.
I. J. Sattinger

Microwave Sensor Systems
Downey, Calif.
J. C. Aukland

National Council on Marine Resources and Engineering Development
Washington, D. C.
Kurt R. Stehling

National Fisheries Institute, Inc.
1614 20th Street N. W.
Washington, D. C. 20009

National Oceanographic Data Center
Washington, D. C.
Leon R. LaPorte

National Oceanographic Instrumentation Center
Washington-Navy Yd. Wash, D. C.

Naval Oceanographic Office
Bathymetry Div.
Washington, D. C. 20390

Naval Oceanographic Office
Coastal Hydrographic Survey Branch
Washington, D. C. 20390

Naval Oceanographic Office
Hydrographic Div.
Washington, D. C. 20390

Naval Oceanographic Office
Sea Ice Branch
Washington, D. C. 20390

Naval Oceanographic Office
Washington, D. C.
George Hanssen

Naval Oceanographic Office
Washington, D. C. 20390
J. C. Wilkerson

Naval Oceanographic Office
Washington, D. C.
Mr. Willard E. Vary

NAVOCEANO
Deep Ocean Surveys Div.
Washington, D. C.

NAVOCEANO
Near Shore Surveys Div.
Washington, D. C.

New Mexico, Univ. of
Albuquerque, New Mexico
Daniel P. Petersen

Nova Univ.
Fort Lauderdale, Fla.

Ocean Data Systems, Inc.
4715 Cordell Avenue
Bethesda, Md. 20014
Mr. John Fry

Ocean Science & Engineering, Inc.
4905 Del Ray Avenue
Bethesda, Md.
W. Bascom, President

Oceanic Research Inst.
6811 La Jolla Blvd.
La Jolla, Calif. 92037
Mr. W. C. Farmer

Oregon State Univ.
Corvallis, Oregon
Mr. William Pearcy

Pacific Fisheries Lab.
Marine Sciences Center
Marine Sciences Drive
Newport, Oregon 97365
Dr. W. J. McNeil, Director

Pacific Marine Fisheries Commission
741 State Office Bldg.
1400 S. W. 5th Avenue
Portland, Oregon 97201
John R. Woodworth, Chairman

Ralston-Purina
San Diego, Calif.
Dr. W. M. Chapman
Director Marine Resources

Scientific Committee on Oceanic Research
International Council of Scientific Unions
P. O. Box 109,
La Jolla, Calif. 92038
W. S. Wooster

Scripps Inst. of Oceanography
La Jolla, Calif.
M. Blackburn & R. Cox

Smithsonian Tropical Research Institute
Panama, Canal Zone

Southern California, Univ. of
Los Angeles, Calif. 90007
Dr. Richard O. Stone
Dept. of Geosciences

Special Committee for Oceanographic Research
United Nations Bldg.
New York, New York

Terry, Dr. Richard D.
1116 Carousel Rd.
Anaheim, Calif.

Virginia Inst. of Marine Sciences
Gloucester Point, Va. 23062
Dr. Maynard M. Nichols

Fisheries Research Labs.
Dept. of
Olympia, Washington
Washington State

Water Pollution Control Labs.
FWPCA
Corvallis, Oregon

Weather Bureau, ESSA
Silver Spring, Md. 20910
Jerome Namis

APPENDIX I

LIST OF INDIVIDUALS AND ORGANIZATIONS RECEIVING QUESTIONNAIRES

GROUP 3 - INSTRUMENT DEVELOPERS

Aerojet-General Corp.
El Monte, Calif.
M. E. Louapre

Aerojet General Corp.
El Monte, Calif.
Mr. A, Edgerton

Airborne Instrument Lab.
Melville, Long Island, New York

Air Force Avionics Lab.
Wright Patterson AFB
Ohio
Paul A. Prior

Air Force Cambridge Research Center
Electronic Systems Division, ESTW
L. G. Hanscom Field
Bedford, Mass.

Arizona, University of
Optical Sciences Center
Tucson, Arizona
Dr. P. N. Slater

Coast Guard, U. S.
Marine Sciences Branch
Washington, D. C.
Lt. Cdr. J. A. McKintosh

CRREL, USA
Hanover, New Hampshire
A. Poulin

Electro-Optical Systems
Pasadena,
California

Ewen Knight Corp.
East Natick, Mass. 01760

Fairchild Space & Defense Systems
300 Robbings Lane
Syosset, New York 11791
Irving Doyle

General Electric Co.
Utica, New York
Light Military Electronics Dept.

General Electric Co.
Space Division
Valley Forge, Pa.
Dr. W. D. Janeff

General Precision, Inc.
Aerospace Systems Division
Wayne, New Jersey

GIMRADA
U. S. Army Engineering Center
Fort Belvoir, Virginia

Geological Survey, U. S.
Washington, D. C. 2-242
Mr. W. Hemphill/G. Stoertz

Geotech Teledyne
3401 Shiloh Road
Garland, Texas
Mr. J. Hamilton

Goddard Inst. for Space Sci.
New York, New York
Dr. P. Thaddeus

Goddard Space Flight Center
Greenbelt, Maryland
Warren A. Hovis

Goddard Space Flight Center
Greenbelt, Maryland 20771
Mr. John Moody

Goddard Space Flight Center
Greenbelt, Maryland
Dr. W. Nordberg

Goddard Space Flight Center
Greenbelt, Maryland
Mr. Harry Press

Goddard Space Flight Center
Greenbelt, Maryland 20771
Oscar Weinstein

Goodyear Aerospace Corp.
Radar Systems Group
Litchfield Park, Arizona

Honeywell, Inc.
St. Paul, Minn.
Dieter Goetze

Hughes Aircraft
Research & Development, Div.
Culver City, Calif.

Hycon
700 Royal Oaks Drive
Monrovia, California 91016

IIT Research Institute
10 West 35th St.
Chicago, Ill. 60616
Mr. Howard Goldman

Infrared Industries, Inc.
P.O. Box 989
Santa Barbara, Calif. 93102
H.O. Hauck

ITEK Corp.
10 Maguire Rd.
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